Playing Code:

Interacting with computers through rhythm

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Abstract

This research project involved the production and public performance of eight audio-visual art works and a corresponding reflective commentary. The aim in creating the artworks was to slow down and translate digital information, in the form of the rhythms and patterns of computer processes, into musical, textual and visual forms. In this reflective commentary, I argue that such processes of playing code offer a distinct form of HCI (human-computer interaction) that has significant musical and critical value in a field that has hitherto been overly dominated by movement, gesture and touch. Through a research process that involved both learning to play the established highly evolved rhythmic artforms of Afro-Cuban and flamenco music, as well as deconstructing data communication signals and developing experimental computer interfaces, I immersed myself in a series of environments in which rhythmic codes were embodied and transmitted through sound. I argue that the systems I developed, by incorporating a variety of cultural traditions - each based upon the transmission of these rhythmical codes - lend what Yuk Hui has described as technodiversity to the field of interactive computer art. Drawing upon postphenomenology and media archaeology, as well as Csikszentmihalyi's concept of flow, I argue for the importance of practice-based methods - making circuits, writing software, performing, exhibiting and studying the music within their localities - in the forging of productive new links between the fields of HCI data communications and diverse global musical traditions. By making data audible and developing experimental new hermeneutic relations with computers, my work suggests productive expansions to our extant relationship with technological artifacts in terms of embodiment, as well as offering practical approaches towards developing technodiversity.

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www.simonblackmore.net/playingcode

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Chapter 1: Introduction

This commentary describes, analyses and reflects on eight audio-visual art works that slow down and translate digital information into musical, textual and visual forms. In these works, the actions of the voice and hands control each bit of data, placing human experience at the centre of the computing process. I argue that whilst this process of playing code demands rhythmical accuracy and entrained repetitive practice from performers, it offers a distinct form of HCI (Human-computer interaction) that has musical and critical value and expands on existing work in this field, as detailed below.

There has been a strong tradition of artists interacting with computers through gestural embodied interactions, from Michel Waisvisz using his hands to manipulate audio samples[1], to Atau Tanaka's making music with muscle sensors[2], and the recent success of the Roli Keyboard[3]. There has also been in a rise in popularity in programming languages for live interaction with computers using keyboards as interfaces including SuperCollider[4]and TidalCycles[5]. However, crucially, much less work has concentrated on developing forms of interaction that focus strictly on rhythm and the temporal domain. This is problematic because many musical systems throughout the world are based on the transmission of rhythmical codes rather than gestural expression. There are significant projects that have addressed this gap such as Enrike Hurtado Mendieta's *Digital Txalaparta* project[6] which allowed performers to play the Basque percussion instrument Txalaparta with a computer.

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[1] Nick Collins and Julio d'Escriván, *The Cambridge Companion to Electronic Music*, Cambridge Companions to Music (Cambridge University Press, 2017). 98
[2] Collins and Escriván. 93.
[3] *Roli Seaboard*, https://roli.com/products/seaboard.
[4] *SuperCollider*, https://supercollider.github.io/.
[5] *Tidalcycles*, https://tidalcycles.org.
[6] Enrike Hurtado and Thor Magnusson, 'Notating The Non-Notateable: Digital Notation Of Txalaparta Practice', 27 May 2016, https://doi.org/10.5281/ZENODO.1289590.

This project aims to address the gap in research between the embodied experience of using the voice and hands to make sounds and the practice of coding computers through symbols. It does this by examining the basic binary rhythmic principles used by computers and using these as the basis for creating a series of installations and performances. These artworks were made with the intention of slowing down computer processes and revealing them to myself, participants and audiences. In order to find a rich musical vocabulary to explore this, I aimed to immerse myself in the equally complex rhythmical musical systems of Afro-Cuban music and flamenco.

Theses aims led to the following two research questions. Firstly, how can computer signals be deconstructed and reconstructed in the form of embodied sound and music in order to develop performances and installations? Secondly, what new encounters in the field of interactive computer art can be developed by playing digital signals to generate sound, text and visual media? I use the word *encounter* here in reference to the French philosopher Gilles Deleuze, who wrote: "[something] in the world forces us to think. This something is an object not of recognition but of a fundamental encounter."[7] It is in this sense that my research aims to challenge conventional notions of how we interact with computers. The works I developed created encounters with computers that abandoned the familiarity of keyboards, GUIs and gestural interfaces in order to focus on exclusively on rhythm, sound and binary code as a means of human-computer interaction. These works have been challenging to play and have brought both frustration and delight to performers and audiences. I argue that these uncomfortable experiences or 'encounters' should be embraced, and that, when developing artworks with new technologies, we should be wary of creating experiences that

[7] Gilles Deleuze, *Difference and Repetition* (New York: Columbia University Press, 1994). 157.

do not provoke or raise questions about our expectations of a given technology. In *Art Encounters Deleuze and Guattari*, artist and writer Simon O'Sullivan clarifies his interpretation of an encounter by comparing it to a non-encounter, which he defines as a confrontation with an art-object that does not surprise us:

> With such a non-encounter our habitual way of being and acting in the world is re-affirmed and reinforced, and as a consequence no thought takes place. Indeed, we might say that representation precisely stymies thought. With a genuine encounter however the contrary is the case. Our typical ways of being in the world are challenged, our systems of knowledge disrupted. We are forced to thought.[8]

By breaking down familiar ways of interacting with computers, I intended to force myself and audiences to think about the mechanics of how they operate.

There is a big leap between analysing micro-temporal computer signals with technical equipment such as oscilloscopes and logic analysers to interpreting them as sound and music. To help guide this process I have studied and encountered musical styles that make frequent use of rhythmic codes to contain and transmit information. These have included flamenco, Cuban Batá, Rumba and Comparsa (Cuban street music). My involvement in these styles of music has given me insights into how rhythms are embodied and used as a basis for improvisation and provided ways to imagine how the micro-temporal world of computing can be interpreted as sound and music. Additionally, studying these musical systems of knowledge and applying some of their ideas, instrumentation and philosophies into my works aims to add technodiversity to my work and to the field of musical HCI more broadly.

[8] Simon O'Sullivan, *Art Encounters Deleuze and Guattari: Thought beyond Representation*, Renewing Philosophy (Basingstoke [England] ; New York: Palgrave Macmillan, 2006). 1.

Technodiversity is a term put forward by philosopher Yuk Hui to describe a need for more diversity within contemporary technology. It is a response to his concern that technology has become increasingly "dominated by the transhumanist imagination of the technological singularity."[9] Hui argues that we urgently need to develop better ways to both understand human technological relations and to find ways to diversify them. My response to this challenge has been to fully absorb myself in the different fields of musical HCI data communications, as well as flamenco and Afro-Cuban music, and to attempt to forge new links and understandings between these hitherto distinct fields. Throughout this thesis I argue for the importance of approaching this through practice-based methods such as making circuits, writing software, performing, exhibiting and studying the music within their localities.

[9] Yuk Hui, *Recursivity and Contingency*, Media Philosophy (London ; New York: Rowman & Littlefield International, 2019). 63.

Contribution to knowledge

Over the course of this research project I have produced, documented, and reflected upon eight new artworks that render digital processes both audible and visible. They explore new ways of interacting with computers through rhythm. The documentation of work – schematics for electronics, code, plans and scores – provide material for these ideas to be recreated and explored further.

My research puts emphasis on practice-based methods of studying: playing the rhythmic patterns of computer signals, designing and making performance interfaces, and learning how to play established and highly evolved rhythmic artforms. I have prioritised the embodied experience of playing rhythms and studying them within the context of their localities – as opposed to analysing them through mathematics or geometry. It is my hope that this approach of playing traditional music alongside developing new technology and artworks provides inspiration to other artists working in computer and electronic arts to place more emphasis on the cultural and physical dimensions of rhythm within musical HCI and to forge more links with diverse global musical traditions.

The works bring together in the same space and time both the cultural semiotic content of data (alphanumeric characters and coloured pixels) and the rhythmic temporal processes of computing. This novel form of embodied coding has the potential to make interesting contributions to fields such as interactive computer music and live coding, which is currently dominated by qwerty keyboard interfaces but has the potential to be re-positioned into the much longer tradition of musically-coded languages. Additionally, through combining the performance of computational processes and production of executable code the works also offer new playful ways of demonstrating and teaching Information Communication Technology.

Research context

My research lies at the intersection of music, visual arts, Human–Computer Interaction (HCI), culture and philosophy. There are a growing number of conferences, festivals and publications dedicated to this convergence of disciplines including ICLC[10], SMC[11], DRHA[12], HLCI[13], SIIDS[14] and Algomech[15]. I have had the privilege of presenting my work at these and will refer throughout this document to both my own work and that of other researcher emerging from this growing movement. My research also draws upon two philosophies of technology: media archaeology and postphenomenology. These theoretical frameworks offer distinct ways of analysing technology and human-technology relations. In very simple terms, media archaeology focuses on the materiality of media technologies and the historic conditions in which they emerge, and postphenomenology deals with the human experience of technology. The historic development and current directions of these theories are well discussed elsewhere (postphenomenology)[16] (media archaeology)[17], but here I will provide my interpretation and use of them.

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[10] *International Conference on Live Coding*, https://iclc.toplap.org/.
[11] *Sound & Music Computing Conference*, http://www.smcnetwork.org/.
[12] *Digital Research in the Humanities and Arts*, http://www.drha.uk/.
[13] *Hybrid Live Coding Interfaces:*, https://hybrid-livecode.pubpub.org/workshop2020.
[14] *Sound, Image and Interaction Design Symposium*, https://siids.arditi.pt/.
[15] *Algomech*, https://algomech.com/.
[16] Robert Rosenberger and Peter-Paul Verbeek, eds., *Postphenomenological Investigations: Essays on Human-Technology Relations*, Postphenomenology and the Philosophy of Technology (Lanham: Lexington Books, 2015).
[17] Erkki Huhtamo and Jussi Parikka, *Media Archaeology Approaches, Applications, and Implications.* (Berkeley: University of California Press, 2011).

Media Archaeology

Media archaeology is a broad field that explores "textual, visual, and auditory archives as well as collections of artifacts, emphasizing both the discursive and the material manifestations of culture."[18] In particular, my research is indebted to the work of media archaeologists who explore time-criticality, microtemporality and rhythm within media devices. The practice and writings that have emerged from this field have provided new vocabulary and methods for exploring the inner workings of computers, and these inspired me to expand them into audio-visual artworks. German theorist Wolfgang Ernst has written and lectured extensively on the relationship between sound, music and computing and the processes by which analogue waves and vibrations become digitised into discreet information. Ernst developed the term *sonicity* to refer to "where time and technology meet"[19] and frequently refers to the musicality embedded in computers. In *Sonic Time Machines*, he writes "[digitized] signals resemble the tradition of music notation; they wait to be algorithmically executed within the central processing unit (CPU) of computers. The CPU is a sonic, highly rhythmical mechanism."[20]

The artist and writer Shintaro Miyazaki has also extensively explored the musicality of computer signals, developing the concept of algorhythmics,[21] a portmanteau of the words algo-

[18] Huhtamo and Parikka. 3
[19] Wolfgang Ernst, *Sonic Time Machines: Explicit Sound, Sirenic Voices, and Implicit Sonicity*, Recursions: Theories of Media, Materiality, and Cultural Techniques (Amsterdam: Amsterdam University Press, 2016). 21
[20] Ernst. 110
[21] Shintaro Miyazaki, 'Algorhythmics: Understanding Micro-Temporality in Computational Cultures', *Computational Culture*, 2012, http://computationalculture.net/article/algorhythmics-understanding-micro-temporality-in-computational-cultures.

rithm and rhythm, used to describe the relationship between rhythm and computing. Miyazaki has expanded on the theoretical connections between computer signals and music by using electromagnetic transducers to make signals audible. In chapter three of this thesis, *listening to technology*, I examine this approach of making data audible. I suggest that although it is possible to gain some understanding of the structure of signals through translating the electromagnetic realm into the auditory, it is impossible to grasp the content of the signals. Media-archaeology offers ways of reflecting on the musicality of computer signals and through my artworks I explored how these ideas could be transformed into artworks so that they could be seen, heard and appreciated.

The image below illustrates how a computer signal could be considered to be rhythmical. The signal on the top line shows the voltage of a serial signal rising and falling. Below shows how the same signal is interpreted by a computer as a stream of zeros and ones that are clocked and converted into ASCII. Through my works I demonstrate how these binary sequences can be conceived as musical notes or silences, where one represents sound and zero represents silence. This is a concept shared by Godfried T. Toussaint, who, in The Geometry of Musical Rhythm, analyses music rhythms "[purely] in durational terms as a symbolic binary sequence of isochronous elements representing sounds and silences."[22] At first I made repeated use of this grid-like idea of rhythm, but studying Afro-Cuban music in particular made me question it. I came to the conclusion that such mathematical analysis could become a hindrance to learning and playing the music, and that it is generally more effective to simply sing or clap rhythms. Consequently, my research has been informed both by mathematical frameworks and by those conceptual frameworks that prioritise the human experience.

[22] Godfried T. Toussaint, *The Geometry of Musical Rhythm: What Makes a 'Good' Rhythm Good?* (Boca Raton, FL: CRC Press, Taylor & Francis Group, 2013). 6.

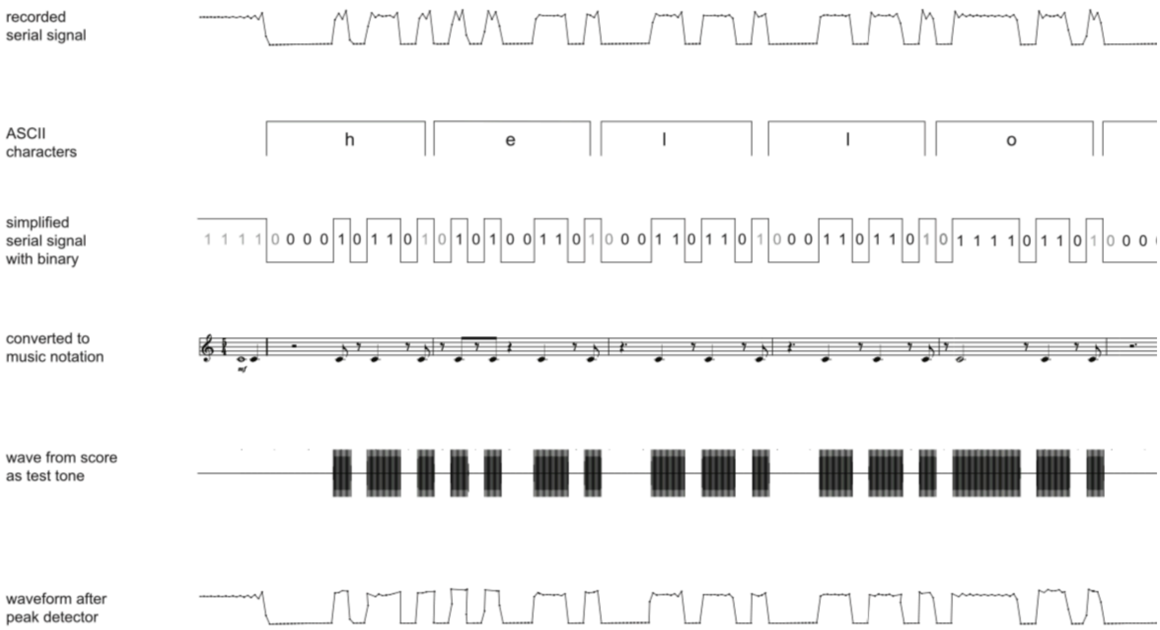

Figure 1 Computer serial signal interpreted as musical rhythm

Postphenomenology

Whilst media archaeology focuses on media devices and attempts to uncover the "hidden agenda of technomathematical artefacts"[23], postphenomenology expands on the philosophy of phenomenology developed by Husserl, Heidegger and Merleau-Ponty. Postphenomenology shares phenomenology's emphasis on human experience and maintains that "the body is our general medium for having a world."[24] However, more specifically, it examines our relationship to technological artifacts and our experience of using them, and explores how these processes of mediation help to shape our relation to the world.

When reflecting upon the works that I produced, I was inspired by recent interpretations of postphenomenology by philosophers, writers and musicians including Peter-Paul Verbeek, Tom Davis and Thor Magnusson. Their interpretations and applications of this theoretical framework helped me to examine the relationships between performers, audiences and technologies within my works. It helped deepen my understanding of what interaction could mean within my practice and how technologies I used and developed shaped the experiences I created. Here, I will further outline the history and my use of postphenomonolgy.

American philosopher Don Ihde's *Technology and Lifeworld*[25] is a foundational text in this field. Here Ihde defines four distinct relations to technological artefacts, which, together, he

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[23] Jussi Parikka, 'Guest Talk on Media Archaeology by Wolfgang Ernst', *Guest Talk on Media Archaeology by Wolfgang Ernst* (blog), 11 October 2009, https://mediacartographies.blogspot.com/2009/11/guest-talk-on-media-archaeology-by.html.

[24] Maurice Merleau-Ponty, *Phenomenology of Perception*, trans. Colin Smith (London: Routledge, 2005). 169.

[25] Don Ihde, *Technology and the Lifeworld: From Garden to Earth*, The Indiana Series in the Philosophy of Technology (Bloomington: Indiana University Press, 1990).

called a Phenomenology of Technics that aims to describe our experience of using technology.

Ihde's first definition is what he calls *embodiment relations*. These are relations with technology that, through repetition, become embodied in such a way that they require little thought from the subject. This refers to the capacity of "technology to become perceptually transparent" [26], or the extent to which the technology being used can fall into the background of one's awareness. Ihde cites glasses, telescopes and musical instruments as examples and uses the following shorthand notation to illustrate the relationship.

Embodiment relations: (human – technology) → world

His second category is *hermeneutic relations*. Ihde describes these as relationships with technology that involve interpreting symbols or representations of reality.[27] He uses the example of a thermometer, as something we interpret rather than see through. The following notation describes this relationship.

Hermeneutic relations: I → (Technology – world)

His third term, *alterity relations*, is used to describe processes that happen when technologies take on a life of their own. Ihde's examples include toys such as spinning tops and robots.[28] in the context of musical HCI we could perhaps think of generative music, glitch music or self-generating synth patches as examples where technology creates surprise and wonder.

[26] Ihde. 86.
[27] Ihde. 21.
[28] Ihde. 100.

Alterity relations: I → Technology – (–world) (may or may not interact with the world).

Lastly, Ihde uses the term *background relations* to describe the technological environment that surrounds us. Here he provides the domestic examples of "home lighting, heating, and cooling systems".[29]

When considering our interactions with musical instruments and computer interfaces, these categories can appear to be too simplistic. For example, to play or to have an embodiment relation with a musical instrument can require years of practice, involving intensive cognitive processes such as learning notes and finger positions. Additionally, musical instruments are not passive like a pair of glasses, but resistant and responsive. This is well argued by Aden Evens, who wrote that "[the] skin of the drum transfers energy back to the drumstick, back to the drummer".[30] We could therefore argue that musical instruments are not embodiment relations and that they never fade into the background, but are continually present, feeding back and generating new alterity relations.

The musician Tom Davis argues that Ihde's categories should "not be interpreted as fixed states, but rather, they describe a continuum of possible states. Following this, it is possible

[29] Ihde. 108.
[30] Aden Evens, *Sound Ideas: Music, Machines, and Experience*, Theory out of Bounds, v. 27 (Minneapolis: University of Minnesota Press, 2005). 159.

for any single interaction with technology to go through multiple states along this continuum".[31] Peter-Paul Verbeek describes this continuum as a moving away from direct experience: "In the spectrum from embodiment via hermeneutic and alterity to background relations, technologies move ever "further away" from the human being."[32]

As my research developed, the tension between these relations became significant. I sought to emphasise embodied relations with voices, hands and instruments whilst simultaneously developing hermeneutic relations with computers. For example, I developed ways of creating ASCII text on a guitar in such a way that I could write text with my eyes closed. Here the experience of playing the instrument was an embodiment relation but reading text that appeared on a screen was a hermeneutic relation. I would argue additionally that the complex feedback a player gets from an acoustic instrument in the form of vibrating strings and overtones etc is an alterity relation.

Verbeek has expanded on Ihde's work to account for these types of complex augmented relations under the term *mediation theory*. He has analysed technologies that similarly combine embodied and hermeneutic relations, citing Google Glass as an example:

> "Google Glass give yet another human- technology configuration. They result in a bifurcation of the human-world relation: On the one hand, smart glasses can be embodied to give an experience of the world, while, on the other hand, they give a representation of the world in a parallel screen. This relation could be called augmentation, combining an embodiment relation and a hermeneutic relation:" [33]

Verbeek provides the following notation to describe this combining of relations:

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[31] Tom Davis, 'Instrumental Intentionality: An Exploration of Mediated Intentionality in Musical Improvisation', *International Journal of Performance Arts and Digital Media* 15, no. 1 (2 January 2019): 70–83, https://doi.org/10.1080/14794713.2018.1545209.
[32] Rosenberger and Verbeek, *Postphenomenological Investigations*. 20.
[33] Peter-Paul Verbeek, 'COVER STORYBeyond Interaction: A Short Introduction to Mediation Theory', *Interactions* 22, no. 3 (27 April 2015): 26–31, https://doi.org/10.1145/2751314.

(human - technology) —> world + human —> (technology - world)

In his essay "Of Epistemic Tools: musical instruments as cognitive extensions", Thor Magnusson argues that digital musical instruments often afford extensions of the mind rather than embodied relations, and therefore "increasingly tend to construe us in a hermeneutic relationship with the world."[34] Therefore, when working with computer music software, cognitive processes often dominate over embodied ones, such that the hands and fingers do less than the brain. Magnusson reflects on audio software and argues that it "has agency and necessarily inheres more cultural specifications than any acoustic instrument."[35] In other words, music software often steers us towards cultural bias and we could therefore argue that it lacks technodiversity. This can be clearly illustrated by opening up any digital audio workstation and checking the default time signature: it will usually be set at 4/4, the most popular time Western time signature. There are many examples of software that challenge these norms and explore microtunings or polyrhythms[36], but I would contest that too often these types of software miss the point of the music they reference. For example, from my experience of studying Afro-Cuban music, it is about much more than manipulating patterns; it is about social relations, collective energy and collective expression. It is for this reason I have placed particular emphasis on embodiment relations and tried to connect those to the hermeneutic dimension of computing. I explored this both individually in works such as *clapping ASCII* and collectively in *Parallel Voices* which was directly influenced by my experience of studying Afro-Cuban music.

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[34] Thor Magnusson, 'Of Epistemic Tools: Musical Instruments as Cognitive Extensions', *Organised Sound* 14, no. 2 (August 2009): 168–76, https://doi.org/10.1017/S1355771809000272.
[35] Magnusson.
[36] *PolyrhythmBeatGenerator*, https://mynoise.net/NoiseMachines/polyrhythmBeatGenerator.php.

My research also draws on the concept of flow as developed by psychologist Mihaly Csikszentmihalyi.[37] He defines flow as "a state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself."[38] Csikszentmihalyi has written extensively on this subject and in *Flow the psychology of optimal experience* he defines a number of conditions that are required to reach a state of flow, such as the activity being a challenging one, requiring skill and having clear goals and feedback. In chapter six, *playing code,* I argue that the works I have developed combine embodied, hermeneutic and alterity relations to try and achieve a sense of flow for the performers.

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[37] Mihaly Csikszentmihalyi, *Finding Flow: The Psychology of Engagement with Everyday Life*, 1st ed, MasterMinds (New York, NY: Basic Books, 1997).
[38] Julia Schüler, 'Flow Experience and Learning', in *Encyclopedia of the Sciences of Learning*, ed. Norbert M. Seel (Boston, MA: Springer US, 2012), 1304–5, https://doi.org/10.1007/978-1-4419-1428-6_523.

Inside machines

The works I produced aim to use musical processes to place performers inside computational processes. The shift in perspective from outside the machine to inside could be theoretically expanded through object-oriented ontology, a school of thought that rejects the privileged perspective of the subject. This has been explored by authors such as Ian Bogost, who, in his book *Alien Phenomonology or What it's like to be a thing*, attempts to view the world from the perspective of components inside an Atari VCS. Bogost observes that the graphics chip's the chips's view of the world is limited to the modulation of electrical signals' "when its internal clock prompts it to witness a change on one of its input registers."[39] I have been inspired by artists that have taken this idea of being inside a machine beyond theory and produced artworks that physically explore the unfolding of computer processes. In Masahiro Miwa's *Reverse simulation music*,[40] musicians become logic gates, and Analivia Cordeiro's[41] pioneering work *Computer Dance* used code to generated dance pieces. In these works, computer processes are simulated and performed, but the process is one way; they are not translated back into code by machines. Felipe Ignacio Noriega and Anne Veinberg's *Codeklavier* project[42] is a good example of the reverse process: here, piano music is performed and subsequently translated into code. My works combine both the performance of computational processes and production of executable code.

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[39] Ian Bogost, *Alien Phenomenology, or, What It's like to Be a Thing*, Posthumanities 20 (Minneapolis: University of Minnesota Press, 2012). 103.
[40] Palle Dahlstedt, 'Action and Perception: Embodying Algorithms and the Extended Mind', in *The Oxford Handbook of Algorithmic Music*, ed. Roger T. Dean and Alex McLean, Oxford Handbooks (Oxford University Press, 2018). 56.
[41] Analivia Cordeiro, *Computer Dance*, 1976 1973, Dance, 1976 1973, https://www.analivia.com.br/computer-dance-3/.
[42] Felipe Ignacio Noriega and Anne Veinberg, 'The Sound of Lambda', in *Proceedings of the 7th ACM SIGPLAN International Workshop on Functional Art, Music, Modeling, and Design*

- *FARM 2019* (the 7th ACM SIGPLAN International Worksop, Berlin, Germany: ACM Press, 2019), 56–60, https://doi.org/10.1145/3331543.3342583.

Rhythmic codes in music

To broaden the scope of my musical references, and to understand how rhythms become incorporated into the body and learn how rhythmical codes function in music, I studied a deliberately chosen selection of musical artforms that utilise repeated rhythmic cycles to transmit information. These included Afro-Cuban folkloric styles of Batá drumming and comparsa (street music), and flamenco palmas, guitar and cajón. Although distinct in historic development and style, these forms are similar in so far as they make frequent use of strict rhythmical cycles in which ambiguity is not tolerated. This selection could, of course, be expanded upon, but each of these traditions is vast and perhaps already too much to include in one body of research. Finally, the connection between rhythmic cycles and bytes of information identifiable within these musical traditions offered a useful musical counterpoint to the study of micro-temporality and rhythm of computer code. The image on the following page shows a serial signal containing a single ASCII character and an audio interpretation of it clapped. This is shown alongside a clapped Afro-Cuban 6/8 clave pattern interpreted as a series of zero and ones. Clave, translated from Spanish as code or key, is a fundamental part of Afro-Cuban music. In essence it is a cycle of beats that define a rhythmic framework that underpins much of the music. It can also refer to the wooden instrument that can be used to play the rhythms, however the patterns can equally be played on a bell, shaker or guataca (hoe blade). There are many different rhythms or clave patterns that are played for different styles of music and these are well documented in books such as The Essence of Afro-Cuban Percussion & Drum Set by Ed Uribe.[43] In the following diagram, I will use a 6/8 clave africana pattern which is one of the oldest and most widely used in Cuba.

[43] Ed Uribe, *The Essence of Afro-Cuban Percussion and Drum Set: Includes the Rhythm Section, Parts for Bass, Piano, Guitar, Horns & Strings ; Rhythms, Songstyles, Techniques, Applications* (Miami, Fla: Warner, 1996).

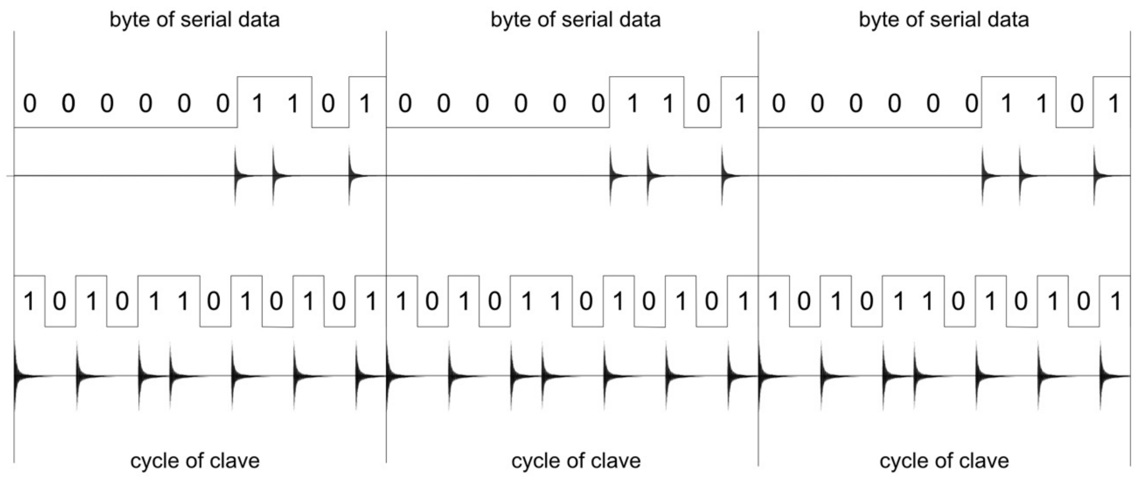

Figure 2 Three bytes of serial data and three cycles of 6/8 clave

Similarities can be seen in the sense that they both share the use of repeated patterns. However it must also be stressed that this is an overly simplistic representation of a clave pattern, which in practice is subdivided more finely and can be compressed and stretched to support a dazzling amount of rhythmic variations.

From tonal languages played on talking drums in Africa, to morse code, the connection between musical rhythm and information theory has a long and rich history. In *The Information*[44], James Gleick makes the connection between the English missionary John F. Carrington's work transcribing the Kele drum language[45] and Claude Shannon's subsequent

[44] James Gleick, *The Information: A History, a Theory, a Flood*, Fourth Estate paperback ed (London: Fourth Estate, 2012).
[45] John F. Carrington, *Talking Drums of Africa* (New York: Negro Universities Press, 1969).

work on information theory[46]. Both Carrington and Shannon explored the amount of redundancy required to send information. Gleik claims that "[for] the African drummers, messages need be about eight times as long as their spoken equivalents".[47] While there is insufficient space here to explore such theoretical claims, I suggest that although the theoretical connections between human rhythm and computing are well documented, they are far less explored in terms of practical musical HCI. This link between drumming and communication was a motivating factor for me to study Cuban Batá drumming.

Afro-Cuban batá

Batá drumming has a long history of language encoded into music.[48] Originating from Yoruba culture in West Africa and evolving in Cuba through the slave trade, it was, and still is, used to communicate to Orishas within the religion of Santeria. It is currently thriving and evolving further in Cuba and Nigeria in both religious and secular contexts [49] and now being studied widely across the world. Within the UK there are study groups both in London and in Manchester, where I had the opportunity to study weekly with musician and ethnomusicologist Dr Christian Weaver.

In *Ancient Text messages of the Yoruba Batá Drum*, Amanda Villepastour writes that "[the] methods developed to transform ordinary Yoruba speech into spoken code and into a coded

[46] C. E. Shannon, 'A Mathematical Theory of Communication', *Bell System Technical Journal* 27, no. 3 (July 1948): 379–423, https://doi.org/10.1002/j.1538-7305.1948.tb01338.x.
[47] Amanda Villepastour, *Ancient Text Messages of the Yorùbá Bàtá Drum: Cracking the Code*, SOAS Musicology Series (Farnham, England ; Burlington, VT: Ashgate, 2010).
[48] Villepastour.
[49] Umi Vaughan and Carlos Aldama, *Carlos Aldama's Life in Batá: Cuba, Diaspora, and the Drum* (Bloomington: Indiana University Press, 2012).

drum language once served the needs of cult secrecy."[50] She describes how, through the widespread adoption of Christianity and Islam, the Batá's encoding method, text, and musical repertoire is in danger of becoming lost and that now it is often used more to "provide dance rhythms than for the transmission of semantic messages".[51]

While developing technology to translate elements of the encoded language of Batá drumming into written forms would be fascinating, it is, unfortunately, far beyond the scope of this research project. It would perhaps also overlook other important aspects of the music which were applicable to my research:

- How to approach the demanding nature of playing polyrhythmic music;
- how clave is used within the music;
- how rhythmic 'conversations' take place within Batá drum ensembles;
- how the tempo in the music changes and who controls this; and
- how the drums use different tonal ranges to fill the sonic spectrum and create polyrhythmic effects.

Studying Batá and Afro-Cuban music more widely had an ongoing impact on the instrumentation, rhythm and general development of the artworks. I will refer to specific examples throughout this reflective commentary, but this included exploring ideas such as using counter rhythms to try to throw me off while playing *Live coding a cajón*, as well as making the decision to not use a computer click track in *Parallel Voices*.

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[50] Villepastour, *Ancient Text Messages of the Yorùbá Bàtá Drum*. 15.
[51] Villepastour. 15.

Flamenco

The rhythms of flamenco have little to do with spoken language and are musical rather than semantic. However, from my experience, being able to sing the rhythms is an important part of teaching, sharing and understanding them. Some of my most memorable encounters with flamenco has been to witness players' ability to tap their foot in combination with hands on a table (nudillos[52]) and to sing a counter rhythm over the top. It is my understanding that this combination of singing and movement of body parts is a fundamental process by which the rhythms become incorporated into the body. Here it is interesting to note that within the Cuban batá music I studied it is frowned upon to tap your foot, but being able to sing the rhythms was fundamental to learning them. These methods of learning rhythms influenced my approach to studying binary patterns, such that I developed techniques of using my hands and voice to sing the ASCII rhythms in *How we Communicate*, while another work, *Clapping a sinewave*, was informed by the flamenco instrument, palmas.[53]

The guitar playing in Cryptoguitar was inspired by how compás is interpreted in flamenco guitar music. Compás is a term used within flamenco to describe the rhythmic cycle within the music,[54] and it is in many ways similar to Afro-Cuban clave acting as a rhythmic framework that supports the music. The rhythmical relationships between clave, compás and data communications will be explored throughout this thesis.

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[52] Nudillos translated as knuckles is a form of flamenco percussion created by tapping on a table. A good example can be seen here https://www.youtube.com/watch?v=2sGc0sKQUZQ
[53] Palmas translated as is also considered an instrument in its own right.
[54] D. E POHREN, *ART OF FLAMENCO.* (Place of publication not identified: CREATESPACE, 2014).

Structure of the thesis

The following four chapters analyse the art works I produced within the context of listening to code, mapping and translating code, rhythmic interaction with computers and playing code. Each piece of work is documented in a chronological order, echoing a sense of the journey taken whilst undertaking the research. It is important to note that although I began this project with research questions and a methodology, the works themselves evolved in scale, audience experience, musicality and instrumentation.

Chapter three, *listening to code*, discusses how the digital transmission of information can be represented through sound and music. I discuss current artistic practices that use transducers to listen to high-speed data signals and use theory from the field of Media Archaeology and argue that musical interpretations offer an alternative approach to revealing the patterns and structures found within binary information. I then describe the technical processes I have used to translate data patterns into music and the machine listening techniques used to translated them into text and sound and reflect on their effectiveness.

Chapter four, *mappings and translations*, explores the translations and mapping of data that occur throughout this research. I argue that although sound alone can contain and transmit information, visual elements provide useful ways to present the translations and mappings to both audiences and performers. To reveal these processes, I have made installations and performances that contain ensembles of technical objects in a wide variety of configurations including projections, circuits, cables, microphones, small LED displays, plotted drawings, musical instruments and people. Through the analysis of two installations and two performances. I argue that my work demonstrates how revealing process impacts the perception of the work.

Chapter five, *rhythmic encounters*, explores the use of rhythm and computer interaction in my work. Here, I argue that rhythm is an important but often neglected part of music and human-computer interaction. I discuss my works with regard to musical qualities such as tempo, phrasing and groove, and argue that these offer a form of sonifying data that is distinctly different to computer process.

Chapter six, *playing code*, explores the creative potential of using embodied actions to play symbolic codes. I discuss the process of turning the played codes into sound, text and image and consider how this working with rhythms and symbols can be developed into a form of compositional restraint and as a form of live coding.

Chapter 2: Methodology

This research involved a broad range of activities from deconstructing computer signals, developing performances and installations, studying flamenco and Afro-Cuban music, and, finally, documenting and reflecting upon the impact of this practice within the context of other contemporary practitioners and relevant theoretical debates. Robin Nelson's dynamic model for mixed mode research, as described in his book *Practice as Research in the Arts*[55], is useful here as it accommodates this broad range of activities and, importantly, considers how the different activities interact. In this model, Nelson cites practitioner knowledge, critical reflection and existing conceptual frameworks as three elements that are all potentially knowledge creating and continually informing each other. The following diagram demonstrates my use of his model.

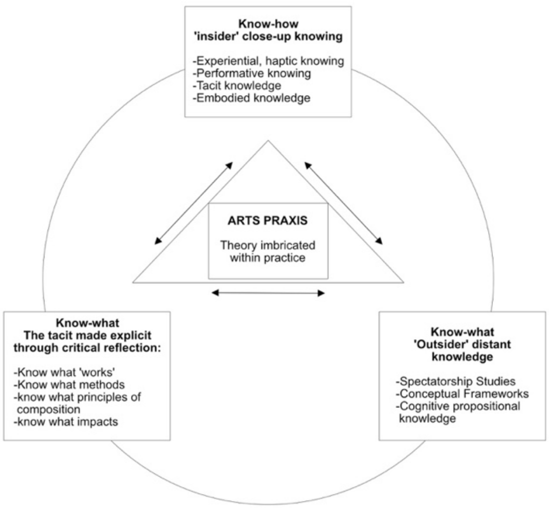

Figure 3 Modes of knowing by Robin Nelson

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[55] Robin Nelson, *Practice as Research in the Arts: Principles, Protocols, Pedagogies, Resistances* (Houndmills, Basingstoke, Hampshire ; New York: Palgrave Macmillan, 2013).

The dynamic interplay between practitioner knowledge, critical reflection and existing conceptual frameworks runs throughout my research. Here I would like to give one example that demonstrates this interplay. As part of my research, I studied and reflected on the technique of playing flamenco percussion and in particular the cajón. A percussion instrument that is based on a basic box, the cajón originates from Peru but is found throughout Latin American music. I studied this instrument with the percussionist Ruven Ruppik and reflected on how it was played (or, in Nelson's terminology, "know what"). In the work *live coding a cajón* I applied this technique to performing with the technology I had developed that translated rhythms to text. After practicing the technique, this knowledge began to develop into a form of tacit knowledge ("know how") and I could use it within a performance without difficulty and it became something that I could reflect on. In other words, the tacit was made explicit through critical reflection. The interaction of these different points of research and practice will be reflected upon in detail further throughout this thesis. Nelson's model, then, provided me with a clear methodology in addressing my primary research objectives, as detailed below.

Analysing existing computer signals and translating them into music and text

During the research process I aimed to get tacit knowledge of computer signals. This echoes Shintaro Miyazaki's argument that the signals that transmit information and form the basis for our digital world should be analysed by the "ears, the hands and the whole body".[56] To

[56] Shintaro Miyazaki, 'Going Beyond the Visible: New Aesthetic as an Aesthetic of Blindness?', in *Postdigital Aesthetics: Art, Computation and Design*, ed. David M. Berry and Michael Dieter. 220.

gain a full understanding of the complex field of data communication I built simple electronic circuits and programmed microcontrollers such as the Arduino[57] to send signals containing ASCII information. Building circuits with my hands and analysing the signals visually with oscilloscopes and computer software gave me embodied knowledge of the process of transmitting computer data. In terms of developing hardware and software to translate rhythms back into code, I first tried a number of systems including software that could run on small computer like a Raspberry Pi and an iPhone 5s. This software was written with OpenFrameworks, "an open source C++ toolkit for creative coding".n[58] This research involved decoding and rewriting protocols and testing audio software and equipment. Within Nelson's framework it would be described as "personal research" and involved "finding out, and sifting, what is already known".[59] In itself this kind of activity does not produce new knowledge, but yet for me it has been an important and practical way to understand the field of data communications. Again, this direct approach brought me closer to the materiality of the subject matter that I was dealing with and gave me the experience required to develop the technology, installations and performances. In terms of Nelson's framework, here the tacit knowledge was made explicit.

Learning to play data via the study of other forms of improvised music

An important part of this research was to gain insider knowledge and experience new encounters with musical traditions that employ the use of rhythmic improvisation. The intention was to use these disciplines to inform how I developed works. I have taken inspiration

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[57] *Arduino*, https://www.arduino.cc/.
[58] *OpenFrameworks*, https://openframeworks.cc/.
[59] Nelson, *Practice as Research in the Arts*. 40.

from writer and musician John Miller Chernoff who, in *African rhythm and African sensibility*[60], describes using the method of participation observation to learn and gain an understanding of Dagomba drumming.

To undertake this component of the research I joined a number of study groups to learn different styles of music. This included flamenco guitar and percussion in Tarifa, Spain with Jose Manuel Leon, Salvador Andrades, Ruven Rippik and Alicia Carrasco, Cuban Batá, Rumba and Comparsa with Christian Weaver in Manchester and in Cuba with Ignacio Calderon, Yosvani Diaz and Chaguito Garzón. The classes were often recorded as audio and where necessary recorded as video. I followed the etiquette that was common across all of the classes I attended: classes can be recorded for private study only and are not to be shared on YouTube or other public forums. During classes I would refrain from taking notes to concentrate on absorbing the information and learning through experience. After attending I would reflect on what I had learnt and experienced, revisit videos and write down my thoughts. I found this the best method to absorb and filter the information in a concise and useful way.

The importance I have placed on practicing art forms is echoed by other researchers in the field of computer arts such as Alex McLean, who, in a paper about contemporary live coding and ancient textiles, argued: "It is not possible to understand a woven structure without actually weaving it."[61] Here, McLean's direct involvement with the practice of weaving and its

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[60] John Miller Chernoff, *African Rhythm and African Sensibility: Aesthetics and Social Action in African Musical Idioms*, Phoenix ed., 11. [Dr.] (Chicago: Univ. of Chicago Press, 20).
[61] Alex McLean, 'Algorithmic Pattern', in *Proceedings of the International Conference on New Interfaces for Musical Expression, Birmingham City University*, 2020, https://www.nime.org/proceedings/2020/nime2020_paper50.pdf.

application to developing programming languages is a good example of both the tacit made explicit through critical reflection and an approach towards technodiversity.

Installations and Performances

Public performances and installations allowed me to test the work with the pressure of an expectant audience. These situations challenged both the reliability of the hardware and software I had developed, as well as my own and others' performance skills, and were critical to developing embodied knowledge of the works.

After each experience I allocated time for critical reflection on the technical, sonic and visual elements the work. This was done through watching video documentation, taking notes and considering the postphenomenological methods described in the introduction above. It was not always pleasant to watch back performances, but doing this kind of critical reflection after the event became an incredibly useful way of thinking about how to develop the next performance.

Producing video documentation to critically reflect on process

The ability to communicate and critically reflect on my processes was an important component of this research. I assessed the development of the work, its musicality and its effect on an audience by talking to peers after sharing video documentation of both experimental tests and performances. I wrote down any significant observations and made audio recordings of longer discussions. The reflective process of examining video documentation with peers enabled me to consider what elements worked or had impact on audiences.

Chapter 3: Listening to code

This chapter discusses how the digital transmission of information can represented through sound and music. I discuss current artistic practices that use transducers to listen to high-speed data signals and use theory from the field of media archaeology to argue that musical interpretations are a significant approach to revealing the patterns and structures found within binary information. I then describe the technical processes I have used to translate data patterns into music and the machine listening techniques used to translate them into text, image and sound and reflect on their effectiveness. Finally, I outline a number of examples of music practice where information is encoded into music and describe my decision to include visual media to articulate the process.

Listening to computer signals

In his essay "Going Beyond the Visible", Shintaro Miyazaki argues that the signals that transmit information and form the basis for our digital world should be analysed by the "ears, the hands and the whole body".[62] He cites a number of historic examples in which listening to machines was crucial to working with them, including Ferranti engineers who in the 1950s ran custom programs on their computers specifically to listen to faults in the machines.[63]

Miyazaki describes this form of listening and analysing information as algorhythmics, which he defines as follows: "[algorhythms] are the timing effects of computation. Such processes are micro-events, which operate on scales and levels that are usually below or beyond our perceptual threshold. Still, they are ubiquitous and operate across all aspects of our life."[64] That is, the increase of speed and reduction of scale of computers has made the sounds that they produce harder to perceive. Artists including Christina Kubisch, Martin Howse and Shintaro Miyazaki have explored the sound of these "algorhythms" by using electromagnetic transducers to convert electromagnetic signals that carry information through the air into sound. In Kubisch's "Electrical Walks,"[65] participants use custom headphones that translate electromagnetic signals into sound. These works enable us to perceive qualities of

[62] Miyazaki, 'Going Beyond the Visible: New Aesthetic as an Aesthetic of Blindness?' 220.
[63] Miyazaki.
[64] Shintaro Miyazaki, 'Algorhythmics: A Diffractive Approach for Understanding Computation', in *The Routledge Companion to Media Studies and Digital Humanities*, ed. Jentery Sayers (Routledge, 2018). 244.
[65] Christina Kubisch, *Electric Walks*, http://www.christinakubisch.de/en/works/electrical_walks.

the location, overall patterns and strength of signals. However, they do not reveal the structure and content of the information carried within the signals because the transmissions occur at such a high speed they appear as clicks and tones.

Media archaeologist Wolfang Ernst also highlights the musicality of computing. Throughout his text *Sonic Time Machines*, he frequently uses musical references to articulate the rhythmic processes that occur inside machines, describing, for instance, the sound of the internet as "discontinuous rhythms; beats rather than waves. The familiar 'flow' of time is being replaced by calculated, 'clocked', mathematical time."[66] Much of Ernst's research operates at a micro level where the world of clocks and bit flipping has indeed little to do with the semantic content it is carrying. In another book Chronopoetics he writes:

> [the] tempor(e)alities of time-critical media can only be understood according to their own operative dimensions through an analysis of technical (time) signals as opposed to cultural (semiotic) signs. In other words, the study of time-critical media necessarily disregards content and focuses instead on temporal processes.[67]

My works aim to bring together both the cultural semiotic content of data and the temporal processes of computing together in the same space and time. This process presents three key challenges. Firstly, there needs to be a shift from the micro-temporality of computers to musical temporality. Computer data is transferred at such high frequencies it can be only be heard at the level of tones and clicks. To be able and hear and interpret the discreet pulses requires slowing down the signal such that the pulses can be heard as rhythms. Secondly, there needs to be a shift in medium. Computer signals are commonly transferred through changes in voltage (wires, circuit boards), light (optical cables) and electromagnetic waves

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[66] Ernst, *Sonic Time Machines*. 34

[67] Wolfgang Ernst, *Chronopoetics: The Temporal Being and Operativity of Technological Media*, Media Philosophy (London ; New York: Rowman & Littlefield International, 2016). xx.

(air). None of these media are inherently sonic, and therefore the signals have to be brought into the sonic realm. Thus, when transducers are used to translated signals from the electro-magnetic domain to the audio, we do not hear the data but an audio representation of it in a different medium. Thirdly, there are layers of semantic abstractions that have to be considered. In making the work I have had to make a number of abstractions, such as sound equalling a digital one and no sound equalling zero. Although these mappings might work, they are always interpretations and have the potential of being read as arbitrary. A good example of this is the use of one and zero to represent logic high and low: while this is commonly used, it could equally be another set of signs, such as cat and dog. The issue of mapping will be considered at greater length in the following chapter.

Reverse engineering computer signals

This research involved examining the rhythmic structure of computer signals, recreating them with sound and then developing appropriate technology to reinterpret the rhythms as coded symbols. The variety of computer signals that could be explored for their musical rhythmic musical potential was overwhelming, from serial to parallel busses, to protocols (RS-232, SPI, I²C), to how the data is line coded (Unipolar, Manchester)[68]. My initial intention was to develop processes to translate a large range of different signals into musical forms and use these as a basis for performances and installations. However, through exhibiting and performing early works, I found that presenting even the simplest protocol easily confused audiences. It therefore seemed unnecessary to work with multiple signals and mappings when there were more pertinent questions to address, such as how to map the data into sound, and what happens with the code once it is produced through music? For this reason, I made repeated use of two ubiquitous computing protocols: serial and parallel data communication. This enabled me to focus on installations, performances and writing music, rather than being completely overwhelmed by the field of data communications.

To study signals I used an oscilloscope alongside a logic analyser to record them into a computer. Software called Logic developed by Salae[69] enabled me to record signals and analyse the semantic content of the signals. It also has the ability to save this data as CSV (comma-separated values) files which can be readily viewed and analysed in other software.

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[68] Behrouz A Forouzan, *Data Communications and Networking* (New York, NY: McGraw-Hill Higher Education, 2013).
[69] 'Logic Analyzers from Saleae - #1 with Professional Engineers', accessed 18 August 2019, https://www.saleae.com/.

This scoping and plotting technology enable one to visualise the signals and extract precise information about their voltage and timing. To slow down and translate the signals into the audio realm I used an audio programming language called SuperCollider[70]. This software has a great deal of flexibility in how it can be used, and, importantly for this work, allowed me to quickly convert data from one form to another. CVS files were able to be converted into MIDI files that could be experimented with in audio software.

The figure below shows a plot of the letter h recorded as an audio signal from a micro-controller programmed to send the letter h. It demonstrates how each letter is sent as voltage moving between 0 and 5 Volts. As illustrated these transitions are interpreted by another machine as either zeros or ones. A total of ten bits are required to send each letter. The first bit known as the start bit is always a zero and the last bit known as a stop bit is always a one. The eight bits between contain the binary information for the letter.

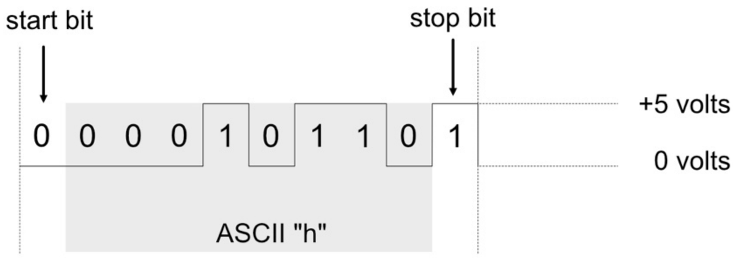

Figure 4 Diagram of serial communication

Generating MIDI files became particularly useful as it allowed me to test out ideas with different instruments within the virtual environment of the computer. Here I made use of standard commercial music making software including Apple's Logic and Ableton Live to

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[70] *SuperCollider*.

be able to simulate what certain rhythmic patterns would sound like played by different instruments.

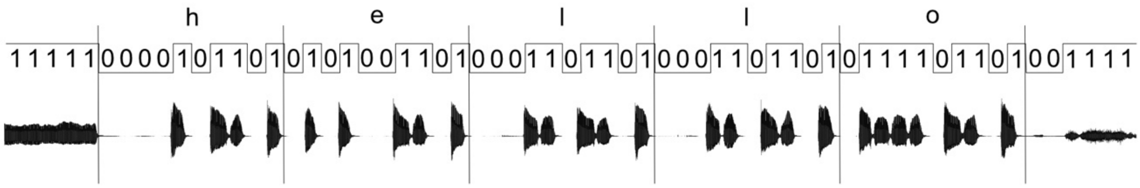

Figure 5 Image of "hello" sung in binary

Having translated the digital signals into sound I worked with microphones, hardware and software to reverse the process and translate sounds back into binary code. This involved research into an area referred to as machine listening. Within this field it is common to analyse the different properties of audio signals such as amplitude and frequency. Some of these aspects of sound can be analysed in real time with analogue circuits and computer software affords more complex forms of analysis including FFT and onset detection.

Amplitude and frequency modulation are two common ways of transferring information. I chose to work exclusively with amplitude modulation as I felt that the abstraction of 'sound equals one, no sound equals zero' was relatively clear and it is simpler to implement from a machine listening perspective than pitch detection, thus incurring less latency. This allowed me to focus on my interest in rhythm, although the exploration of frequency modulation would be interesting for future research.

The works produced during this research used different techniques to translate the amplitude of the sound into binary information. These ranged from software solutions such as simple amplitude detection algorithms (*Parallel Voices*), to MIDI drum trigger modules (*Duplex Drumming*), and the creation of analogue electronic amplitude detection circuits (*Cryptoguitar*).

These decisions were based on what was practical for the context of the work and are described further below under each work. For instance, though, when I exhibited *clapping ASCII* at Supernormal Festival, I used a software RMS audio peak detector to detect the claps. This meant that in some very noisy situations the installation failed to work properly, so therefore when performing *Clapping a Sinewave* at Algomech I used a more computational complex onset detection algorithm to give me the best chance of the piece working.
Sounds produced from musical instruments are rarely either on or off and have varying forms of attacks and decay. The largest issue when producing this work was dealing with the various decay times of instruments. I worked with sounds ranging from the short decays produced by the human voice and percussion (shown above) to the much longer decays produced by the ringing of a guitar string.

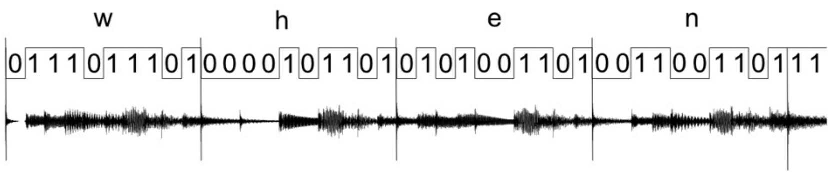

Figure 6 Waveform of the word "when" played on the guitar.

Another important factor when using microphones to detect audio amplitude is the reverberation of the room and the distance of the microphone from the source. This effect of the space on producing accurate readings was highlighted during an installation I did at Audiograft wherein I played back a recording of my voice producing binary information and transmitted this to microphone. Here the intention was to pick up the binary information from my voice alongside some interference from the space. The translation of voice to ASCII text was presented on a both a live circuit and a screen that showed a printout of the past hour.

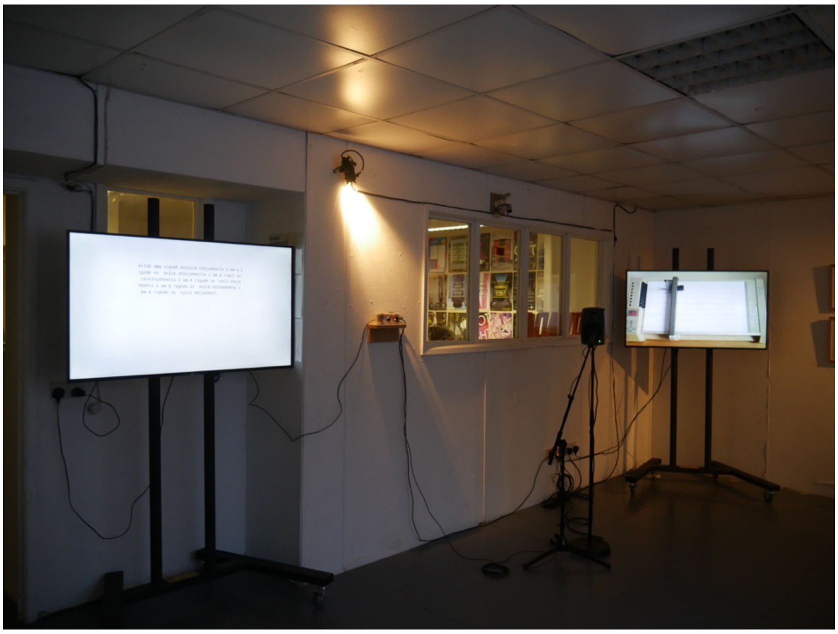

Figure 7 How we communicate, Audiograft 2018

Figure 8 Speaker/microphone placement in the Audiograft installation

By moving the microphone closer and further from the speaker I had the ability to tune how much noise from the space entered into the translation part of the circuit and ended up settling on about 5 cm as this allowed for about 50% to %80 of the letters to appear depending on how noisy the space was. This worked well as it was important that the work was open to error rather than being a pre-recorded work that always produced the same results.

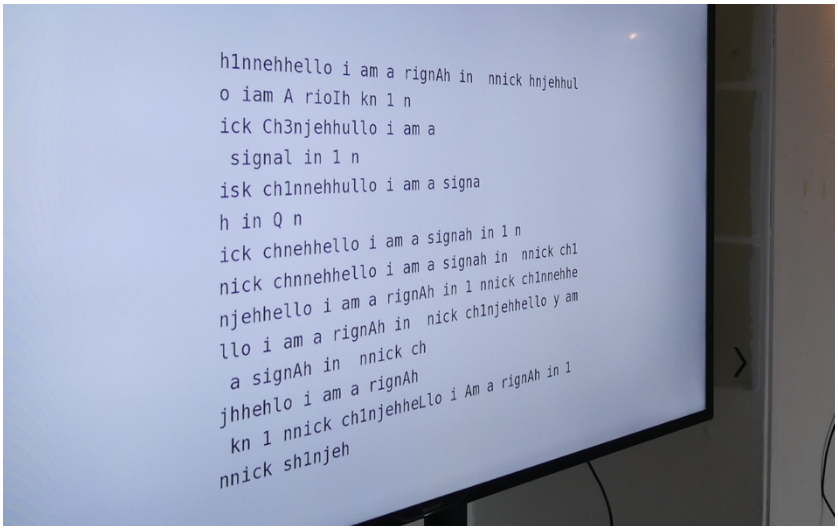

Figure 9 Text on a monitor during noisy period of the Audiograft installation

The more I reflected on performances and showed my documentation to peers, the more it became clear that the translation process from sound to text within the work was difficult enough to understand without the additional problem of audio not triggering the system effectively due to acoustics. This led me to move towards using industry tested solutions such as MIDI drum triggers and MIDI clocks to get the most robust timing and triggering solutions I could, enabling me develop works such as *Duplex Drumming*.

The successful results with commercially available MIDI percussion equipment prompted me to develop hardware that adopted MIDI standards such as MIDI CLOCK and Note On and Note Off. I found that adapting my work to these standards allowed me to be very experimental in how I was able to work. The MIDI standard with its ability to merge signals like a clock from one source and trigger information from another allowed me to test things in many different configurations. For example, I could plug an electronic drum kit into the hardware I had developed and at the same time control the timing of my hardware from software such Ableton Live.

Code in Music

Having translated the computer rhythms into playable rhythms raises the question of how this might be interpreted by players and audiences. Do these elaborate techniques of slowing down and sonifying of data make it any easier to interpretable than the methods of Miyazaki, Howse and Kubich?

The perception of semantic information within sound has a long history and is debated within many fields including ecological psychoacoustics (a listener's ability to the length of dropped rod)[71] sonification (weather data rendered as sound)[72] and musicology (music imitating sounds such as birdsong)[73]. *To* my knowledge there is not a study that encompasses the diverse fields referenced alongside language embedded into drumming as researched by Amanda Villepastour[74]. In what follows I will partially address this gap.

The broad field of sonification, which can described as non-speech audio to convey information, is clearly of great relevance as it deals specifically with making sound from data. This is afforded by the ability of computers to process more or less anything into sound. In their essay "A Theory of Sonification", Walker and Nees state that "major limiting factors in

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[71] Marc Leman, *Embodied Music Cognition and Mediation Technology* (Cambridge, Mass: MIT Press, 2008), 167.

[72] Thomas Hermann, Andy Hunt, and John G. Neuhoff, eds., *The Sonification Handbook* (Berlin: Logos Verlag, 2011). 460.

[73] Raymond Monelle, *Linguistics and Semiotics in Music*, Contemporary Music Studies 5 (Chur: Harwood, 1992).

[74] Villepastour, *Ancient Text Messages of the Yorùbá Bàtá Drum*.

the deployment of sonifications have been, and will continue to be, the perceptual and information processing capabilities of the human listener.”[75]

Examples from this field demonstrate that while it possible to extract meaning from sound and music, it often requires a high level of skill from the listener. For example, a physician’s interpretation of the sound from a stethoscope is much more refined than that of a non-physician. During my research I developed the ability to hear a letter in a clapped rhythm by becoming familiar ASCII alphabet, but there are far too many abstractions involved for this to be legible to an audience. This process of needing to understand the medium to understand a message is succinctly articulated by Alan Kay, the inventor of the familiar Graphical User Interface: “[anyone] who wishes to receive a message embedded in a medium must first have internalized the medium“.[76]

Immersing myself in Cuban Batá also demonstrated to me that learning to listen to signals within complex music takes a significance amount of practice. Much like learning an oral language, what starts as jumble of sounds slowly takes a form that can be cognitively processed. My teacher, Dr Christian Weaver, often referred to the importance of “selective listening”[77] which in the context of playing Batá involves the ability to listen out for certain signals from the one drum, change rhythm and then completely ignore the music as it will more than likely be confusing and off-putting.

[75] Bruce N. Walker and Michael A. Ness, ‘Theory of Sonification’, in *The Sonification Handbook*, ed. Thomas Hermann, Andy Hunt, and John G. Neuhoff (Berlin: Logos Verlag, 2011). 27.
[76] Conan Xin, ‘“User Interface, a Personal View” by Alan Kay’, https://medium.com/@conanxin/user-interface-a-personal-view-by-alan-kay-85ef0ac6a8a3.
[77] Christian Weaver, Interview with Dr Christian Weaver, 26 September 2020.

In her book *Ancient text messages of the Yorùbá bàtá drum*, Amanda Villepastour describes how the Yorùbán language is encoded into drumming patterns and how it is now a dying art due to the decreasing amount of people who understand Yorùbán. She argues that players have gravitated to playing danceable rhythms as opposed to reciting free flowing text.[78]

Villepastour's research identifies that information encoded in batá drumming is only understandable to those who understand the language well enough. My experience of studying Cuban batá in both Cuba and the UK is that there is little understanding of what is being semantically spoken through the drums, and the spoken language has evolved into a musical language.

European classical music has its own tradition of encoding layers of meaning into sound which has been popular at least since the 17th century. The composer Johann Sebastian Bach famously encoded his name into his instrumental works of music.[79] These types of musical cryptograms have continued to be explored by many composers, including Messiaen, who encoded a dizzying amount of information in his work *Méditations*. This work contains no lyrics but is so densely full of information that the organist Andrew Shenton has dedicated a book to analysing and decoding it. The music contains numerous devices including a "musical alphabet in which a rhythmicized pitch is assigned to each letter of the roman alphabet."[80] The ability to be able to listen out for and translate the letters encoded into Messiaen's work is undoubtedly well beyond the perceptual and information processing capabilities of

[78] Villepastour, *Ancient Text Messages of the Yorùbá Bàtá Drum*.
[79] Ruth Tatlow, *Bach and the Riddle of the Number Alphabet* (Cambridge ; New York: Cambridge University Press, 1991).
[80] Andrew Shenton, *Olivier Messiaen's System of Signs: Notes towards Understanding His Music* (Aldershot, England ; Burlington, VT: Ashgate, 2008). 13.

most people. However, as suggested by Shenton, it is “worth studying in depth because of its intrinsic interest as a musical technique”.[81]

[81] Shentnon. 13.

Conclusion

I have discussed the issues associated with listening to semantic information within computer process and described my process of slowing this down in such a way that it becomes possible to play rhythms the rhythmic patterns that contain information. I argued how there are major obstacles are translating and revealing computer signals, the shift in temporality, the shift in medium, and layers of semantic abstractions. I gave examples of how through repeated practice, semantical information can be embedded into sound, learnt played and interpreted by both computers and humans. However, I have argued that this process always takes time and commitment. For this reason, I decided to include visual presentation in my installations and performances. This will be the focus of the following chapter.

Chapter 4: Transmissions, mappings and encounters

This chapter explores the translations and mapping of data that occur throughout the works produced during this research. Although, as I have described, sound alone can contain and transmit semantic information, visual media provided an effective way to present the translations and mappings. The installations and performances I produced contained ensembles of technical objects in a wide variety of configurations including projections, screens, circuits, cables, microphones, small LED displays, plotted drawings, musical instruments and people. Focussing on the analysis of two installations and two performances I discuss the mappings used and how revealing mapping processes impacts an audiences perception of the work.

Mappings and translations

Binary data has the ability to be translated into multiple symbols including ASCII characters, colours and sound. This flexible mapping of digital content has been theorised in numerous ways. Katherine Hayles draws on the work of Jacques Derrida to describe the process through semiotics as a "flexible chain of markers"[82] that extend the "gap that separates speaking from writing"[83]. Within the arts, the terms transmutability,[84] transubstantiation and transmateriality[85] have been used to describe the many art works that exploit this malleability of data and its affordance to be repurposed from one media into another.

Translating data into visual or audible forms is often referred to as visualisations or sonifications, and such representations have become increasingly widespread. While visualisations of data have been described in books and media articles as beautiful,[86] truthful[87] and spectacular,[88] artworks that explore this have been also susceptible to the criticism of being formulaic and ultimately arbitrary. This quote taken from the artist Tom Moody's blog sums up this perspective:

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[82] Katherine Hayles, *My Mother Was a Computer: Digital Subjects and Literary Texts* (Chicago: University of Chicago Press, 2005). 31.
[83] Hayles. 43.
[84] Catarina Lee and Luísa Ribas, 'On the Transmutability of Textual Data: Concept and Practices', *Journal of Science and Technology of the Arts* 8, no. 1 (30 November 2016): 45, https://doi.org/10.7559/citarj.v8i1.221.
[85] Ulrik Ekman, ed., *Throughout: Art and Culture Emerging with Ubiquitous Computing* (Cambridge, MA: MIT Press, 2013).
[86] David McCandless, *Information Is Beautiful: Revised, Recalculated Ans Reimagined* (London: William Collins, 2012).
[87] Alberto Cairo, *The Truthful Art: Data, Charts, and Maps for Communication* (Indianapolis: New Riders, 2016).
[88] 'Solar Equation - A Spectacular Installation by Rafael Lozano-Hemmer Comes to the MNBAQ', 26 September 2018, https://markets.businessinsider.com/news/stocks/solar-equation-a-spectacular-installation-by-rafael-lozano-hemmer-comes-to-the-mnbaq-1027567246.

“It's usually: "hey, i did X to Y and now it's Z...get it??!" [T]he perfect example ... is that piece where its a choir singing the NASDAQ stock exchange graph as music... Who cares? Is there anything interesting going on beyond the punchline?[89]

This criticism is extreme, but it is also a clear example of how the endless possibilities of mapping data can become meaningless. This is perhaps why many artists choose more personal data to work with: in *The Sound of Ebay*[90], Hands Bernhard translated personal Ebay data into music, and in Rafael Lozano Hemmer’s *Pulse Room*[91], audience members’ pulses are translated into pulsating lights. The mapping is arbitrary, but the connection is personal.

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[89] Moody Tom, ‘VVork and XYZ Art’, 30 April 2007, http://www.digitalmediatree.com/tom-moody/?40531.
[90] Hans Bernhard, *The Sound of Ebay*, 2008, 2008, http://classic.rhizome.org/artbase/artwork/48120/.
[91] Rafael Lozano Hemmer, *Pulse Room*, 2006, 2006, https://www.lozano-hemmer.com/pulse_room.php.

Multimodal installations

My works avoided arbitrary mappings by explicitly copying how computer signals are mapped to symbolic computational forms. For example, the serial data structure used in many of the works was precisely copied and the mapping of binary to ASCII was not arbitrary but a standard embedded into many computer languages.

```
void ofApp::processASCII(){

processResult = ((bit8*1) + (bit7*2) + (bit6*4) + (bit5*8) + (bit4*16) + (bit3*32) + (bit2*64) + (bit1*128));

typeStr.append(1, (char)processResult);

}
```

Figure 10 C++ code used for translating binary into an ASCII character

The works also aimed to reveal each stage of the translation process, from sound triggering a binary state through to its transformation into text, colour, and image. The presentation of a range of activities, processes and objects brought many challenges of presentation and legibility. The playing of musical instruments emphasised embodied relations, whereas screens emphasised hermeneutic relations. The fact that the pieces were continually in flux and processes were made visible also raised the important issue of whether the works were read on a technical rather than an imaginative level. Florian Cramer wrote in *Words Make Flesh*, "the wider the gap between code and perception, the wilder the imagination."[92] If this is the case, then it could be argued that revealing process can remove the scope for imaginative interpretations of the work. I found that the more complex my works became both musically and visually the more the open they were for imaginative interpretation. This was my experience

[92] Florian Cramer, *Words Made Flesh: Code, Culture, Imagination. Rotterdam: Piet Zwart Institute.* (Piet Zwart Institute, 2005), https://www.netzliteratur.net/cramer/wordsmadeflesh-pdf.pdf. 8.

from showing peers video experiments of *Cryptoguitar*. They told me they gave up trying to understand the mapping process and began to let their minds wander and consider what it is to be human, how computers work and music and creativity more broadly. Here the process was revealed but there was so much additional information in the form of melodies and fast flowing text it was hard to follow. Revealing process also has its critics within the world of experimental music: Denis Smalley, an influential figure in acousmatic music, developed the term 'technological listening' to describe "when a listener 'perceives' the technology or technique behind the music rather than the music itself, perhaps to such an extent that true musical meaning is blocked."[93]

While my works sought to create new encounters between people and machines, rather than "true musical" meanings, Smalley makes an important point in that revealing processes has the potential of dramatically changing how an artwork is interpreted. Through feedback from audiences I found that my works were often scrutinised in terms of functionality rather than meaning. In other words, they were sometimes interpreted as a cybernetic systems and people asked not, "what is this thing?" but "what does it do?"[94]

The kinds of questions that often arise here are well summarised in a study called *Digital Musical Interactions: Performer–system relationships and their perception by spectators* by Gurevich and Fyans.[95] Below I have reworded their questions from an audience's perspective.

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[93] Denis Smalley, 'Spectromorphology: Explaining Sound-Shapes', *s*, no. 2 (August 1997): 109, https://doi.org/10.1017/S1355771897009059.
[94] W. Ross Ashby, *An Introduction to Cybernetics*, 2015. 1.
[95] Michael Gurevich and A. Cavan Fyans, 'Digital Musical Interactions: Performer–System Relationships and Their Perception by Spectators', *Organised Sound* 16, no. 2 (August 2011): 166–75, https://doi.org/10.1017/S1355771811000112.

- Address: Is the performer directing communication to the system?
- Attention: Is the system is responding to the performer?
- Action: How is the user controlling the system?
- Alignment: How do we know that the system is doing the right thing?
- Accident: How do we know when the performer or the system has made a mistake?

These questions provide useful prompts to reflect on how works might be perceived. I will continue to refer to them in the following analysis of two installations and two performances.

Two installations

I produced two installations where the physical action of clapping and singing was translated into binary data and further into text. These were configured in such ways that the audience had very different relationships to the works.

Clapping ASCII was a work where audience members were invited to directly interact with the system by creating text on a screen by clapping binary ASCII rhythms. The aim was to create a work where participants could take part and embody the rhythms of a serial signal. Instructions and scores were presented on music stands, and participants could choose a word, clap out the appropriate rhythms and see each letter appear on a monitor.

Figure 11 Clapping ASCII, Here East, 2016

The system was designed in a such a way that meant each letter had to be clapped one at a time. Participants often approached the work as a game and set themselves the task of clapping out a particular word. They celebrated if they managed to make a complete word and got a little frustrated if they didn't. In this work, the audience became the performers and the graphical feedback made it clear that the system was responding to them. There were occasionally alignment issues where perhaps someone clapped out of time, or not loudly enough and what occurred on the screen was unexpected, but the system was clear and accessible.

Whilst *Clapping ASCII* clearly articulated a data transmission process and the mappings involved, I felt that the output did not have a strong or meaningful enough quality to encourage sustained engagement. This could be developed through scale in interesting ways, for example, making the text appear more beautifully, as in Rafael Lozano Hemmer's work, *Cloud Display*,[96] in which the audience's voice is translated into text and appears as dry ice.

The installation *How we communicate* explored a very different approach to audience interaction. In this installation a stream of pre-recorded sung binary patterns was played through a speaker, this audio was picked up by a microphone, and a circuit mounted on the wall translated the sound into text. In this case, the audience did not directly create the signal but instead witnessed a pre-recorded voice being translated live into a digital signal and further into text. As discussed in chapter three, any noise produced in the space had the potential to interfere with the signal causing misprints and errors in the output.

Configuring the installation so that the translations happened live in the space meant that some people wanted a more direct encounter with the work. On one occasion the microphone was moved away from the speaker so someone could use it. Another person loved the idea so much they developed an online *Choose Your Own Adventure* narrative about being trapped in a computer and wanted to test it with the system. These acts obviously disrupted

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[96] Rafael Lozano Hemmer, *Cloud Display*, 2019, Multimedia, 2019, http://atmospheric-memory.com/.

the installation more than I had anticipated, but the fact that some audience members wanted to directly interact with the work demonstrated the playful potential of the interfaces.

I witnessed audiences spending time with the installation, unpicking how it worked, finding out why errors were appearing on the screen, and examining plots of the signals. In this respect, the multimodal dimension of the installation was successful at revealing the different mapping stages. It was also noticeable that some people would spend time in groups unpacking the mappings and processes together.

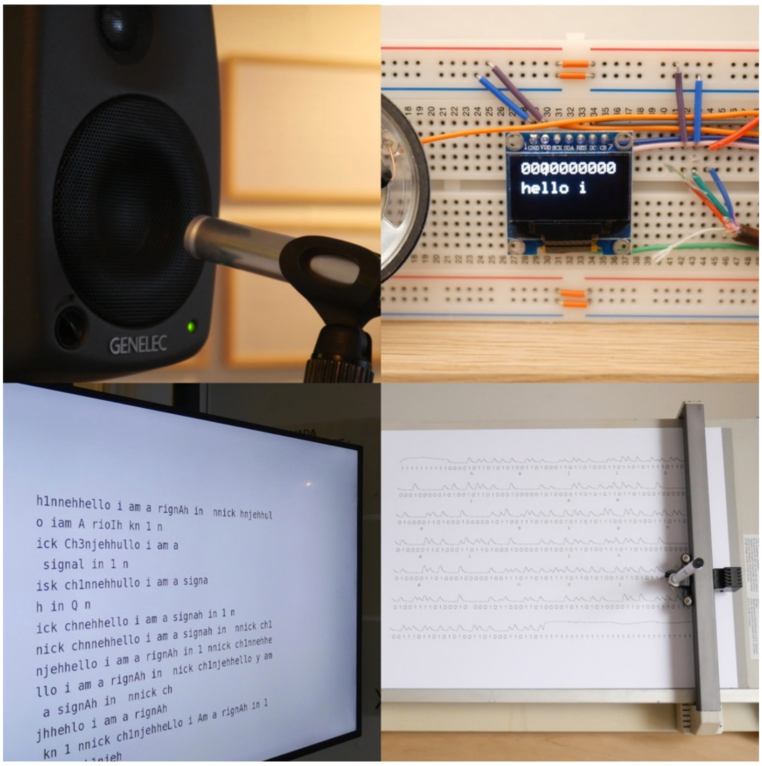

Figure 12 Audiograft installation 2018 – four different modalities

Two performances

To analyse how the presentation of mappings and translations have been perceived in performances I will contrast two works that were performed in an experimental concert context. Both performances had seated audiences and full screen projections behind the performers. In both instances I tried to avoid explaining the work, and to allow the performance itself to reveal the process.

How we communicate was a performance whereby binary rhythms were sung into a microphone and translated into text which was projected behind me.

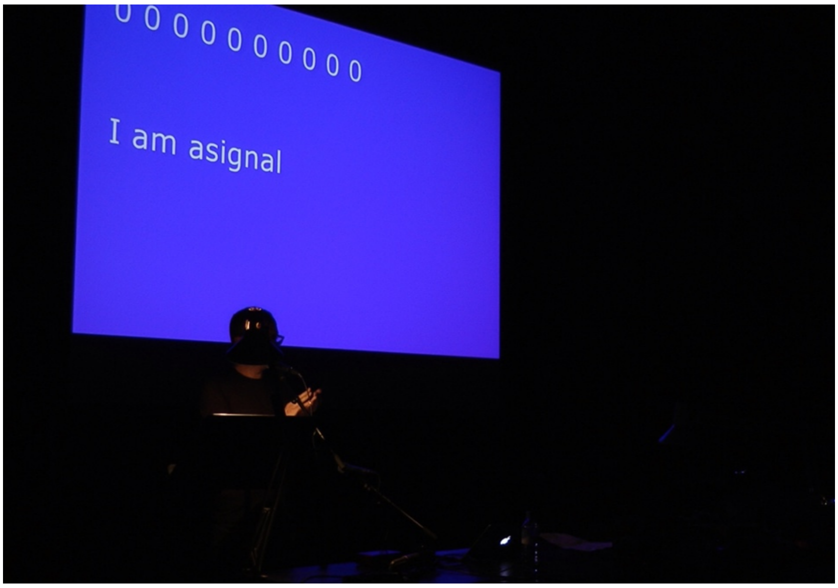

Figure 13 How we communicate, DIEM 2017

This work was set to an audible click track and I performed it using a vocal percussion technique from South India called konnakol.[97] This technique had been shown to me by my flamenco percussion teacher Ruven Ruppik to help internalise long rhythms. My hands orientated the rhythm, and I used the sound syllables ta and ka to 'sing' the data. Every time I made a sound a zero turned to one on the screen behind me and by articulating the correct patterns a stream of text appeared on the screen. The performance had a lack of fluency and I made mistakes, but I had learned the code for delete, so my ability to do this raised a few laughs. I began the performance by making the rhythm to write hello in Danish (hej) and then wrote the line "I am a signal in a noisy channel". Although the work was painfully slow, it offered a clarity of all of the mapping stages. In Don Ihde's terminology, it seemed that the hermeneutic relations and the mappings in the work were legible to the audience. However, the embodied relationship with my voice and technology felt a little monotonous and not fluid enough to be enjoyable in any musical sense. This aspect of the work could be developed through practice and changes in dynamics and tempo of the voice. There is also a well-established tradition in performance art of using repetition to push audiences to their limits, including works by companies such as Forced Entertainment.[98] Extreme repetition and duration could be a rich area to explore but I made a decision to concentrate on creating shorter instrumental pieces such as *Duplex Drumming, Parallel Voices* and *Cryptoguitar*. In *Duplex Drumming*, this embodied/hermeneutic dynamic moved to the other extreme; the drummers seemed to have an embodied experience of producing the text on the screens but due to the speed at which they executed it, the additional sounds of cymbals, the mapping process was harder to follow.

[97] David P. Nelson, *Solkaṭṭu Manual: An Introduction to the Rhythmic Language of South Indian Music* (Middletown, CT: Wesleyan University Press, 2008).
[98] Tim Etchells, *Certain Fragments: Contemporary Performance and Forced Entertainment* (London ; New York: Routledge, 1999).

A later work, *Parallel Voices*, revealed the conversion of binary data into text, colour and image in what I felt was a faster and more impactful way than *How we communicate*. This performance piece was for eight vocalists: the amplitude of each voice triggered a zero or one and the bits could be processed into a byte. Each of the eight bits represented as zeros or ones were clearly displayed above each singer's head and each byte of data produced by the singers was translated into an ASCII character, colour or coloured pixels.

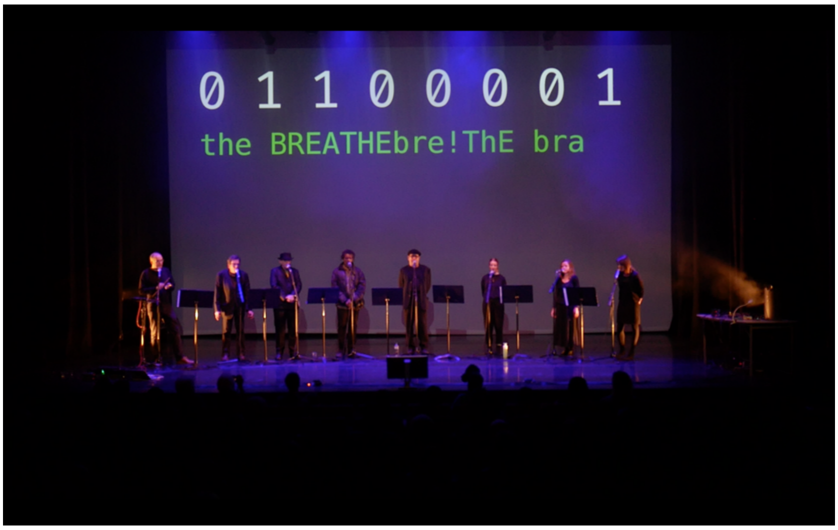

Figure 14 Parallel Voices performed at the Lowry 2019 – ASCII mode

The piece began with each performer taking it in turns to make a vocal sound which turned into binary zero or one on the screen. This clear indicator aimed to highlight the correspondence between voice and the binary data, demonstrating to the audience that the performers were communicating with the system. I controlled the tempo of the piece by tapping a clave and with each tap the state of the bits of the bits were processed. Again, in this work, errors occurred and were clearly revealed through spelling mistakes. These provided an indicator that the system was working, and that mistakes were the fault of the group.

As the piece progressed, the mapping from the singer's voices to binary to the visuals projected on through to colours and pixels on the screen became more complex and more arbitrary. To produce colours, I had to make decisions like how big the pixels would be and develop custom functions to simulate three-bit and six-bit colour.

Figure 15 Parallel Voices performed at the Lowry 2019 – 3bit colour mode

This additional use of colour and images alongside ASCII text made this piece distinct from the other pieces and arguably more visually powerful. The large projected display lit up the entire theatre so having the ability to change the atmosphere of the room shifting combinations of voices was dramatic. This is good example of where the embodied action of the voice, performs alterity relation. Producing this work made me realise I had perhaps been so focused on text and code that I had underestimated the potential of a painterly approach. When producing pixels, mistakes resulted in something interesting and beautiful, as opposed to a stream of illegible text. However, these visuals were also noted by one audience member as disappointing, which is understandable if we compare eight-bit graphics with sound-responsive animations or film. The chunky pixels and simple colours gave a very particular retro aesthetic to the piece. While developing the work, unusual constraints emerged, such as the need for the singers to take a deep breath before rendering a line of pixels.

From written audience feedback taken after the performance, it was apparent that the increase in speed of data transmission and multiple mappings made the work more difficult for an audience to decode than a work like *How we communicate.* This was summarised by use of words such as "confused and magic". These two works represent different approaches to how digital signals can be translated into sound, music and visual media. One approach is slow and clear; the other is fast and potentially confusing.

During the production of each work I aimed to make the mappings clear. On reflection, there is a danger that this can lead to slow and boring performances. Perhaps works should simply strive for more magic – or alterity relations. In *Parallel Voices* this could perhaps be developed through longer poetic flows of text, more beautiful harmonies, a powerful image or the system beginning to have a life of its own. My experience of watching Afro-Cuban music or flamenco performances highlights how complexity can be embedded into works without the need to be explained to an audience. The audible codes from singers and musicians, visual codes from dancers are all present and often intricately woven together around strict rhythmic structures. It takes years to gain the ability to unpick these cues and rhythmic interactions, and yet, the pieces can be equally be enjoyed by audiences without them ever attempting to do so.

A rewarding aspect of working on *Parallel Voices* was the enthusiasm of the performers. During the rehearsals I discovered how excited they became when they began to understand how their embodied relations with the system related to the hermeneutical relations of producing text, pixels etc. This took a while to click but when it did it inspired them to come up with new possibilities for the system. This again highlighted the work's potential to create new encounters with technology that enable people to understand how digital signals work by themselves becoming such signals.

Conclusion

The context of installations offered greater temporal and spatial possibilities to work with than short performances. This allowed for audiences to engage in the work for longer periods of time, and to have conversations whilst engaging in the work. What is lacking in the excitement of being in a live performance is compensated for by having more time to reflect on the processes involved. In this sense audiences of installations have the opportunity to become reflective practitioners.

From different sources of feedback, it transpired that the more complex the audio input the more confusion there is over the mapping process. In *Parallel Voices*, for instance, it was often assumed the pitch of the voice had something to do with making the colours. I concluded that confusion over process is not necessarily a bad thing and can lead to richer experiences; in this sense artworks are distinct from technical demonstrations.

Some of the strongest engagements and understandings of the work came through people trying to use the systems. However, these systems need to be more interesting than presented in *Clapping ASCII*. I discovered that percussionists enjoyed creating rhythmic ASCII patterns because they can experiment playing them in different ways. This could be creating a letter with the snare while playing a different groove with the hi-hat and bass drum. When presenting this to audiences, there is a balance to be struck: what is most engaging for a performer is not what is most comprehensible to an audience.

The interpretations, mappings and outcomes possible from these processes are vast and offer new ways of rhythmically interacting with computers. This could be expanded on and developed further through open source code, the release of software, hardware and musical scores. This would allow the work to be accessed and played by a wide range of people who would find new ways of working with the technology and offer more technodiversity and deeper understanding of how computers work. Although the works were conceived of as encounters that intended to make people rethink familiar computer interfaces, I frequently discovered that once people understood how the systems worked, they wanted to explore them further. The embracing and exploration of these interfaces demonstrates the potential they have to develop further understandings of digital technologies.

Chapter 5: Rhythmic encounters

This chapter argues for a greater focus on human rhythmic interaction within contemporary computer music. I explore concepts of rhythm from the technodiverse fields of interactive computer music, data communication theory, Cuban Batá and flamenco. I examine the dynamic interplay between musicians and computers within my own works and contest that through combining these different understandings of rhythm I have developed new rhythmic encounters with computers that focus on the human body.

For human rhythm in computer music

In the book *Gesture and Speech*, French archaeologist Andre Leroi Gourhan argues how humans evolved through the embodied practices of walking and making, and not through disembodied cognitive development. Tim Ingold summarises this theory succinctly: "[to] understand the evolution of humanity we have therefore to begin with the feet instead of with the brain."[99] A full study on rhythm and hominization is clearly beyond the scope of this research project, but I would argue nonetheless that our ability to create and manipulate time through rhythm is important, challenging, enjoyable, and often under-exploited in musical HCI.

Extant projects in this field, in which the demands of human rhythm and timing are put to the test, include including Amy Alexander's *Percussive Image Gestural System*[100] and Enrike Hurtado Mendieta's *Digital Txalaparta* project.[101] In the book *New Directions in Music and Human-Computer Interaction*,[102] a project called *Interactive Tango Milonga* by Courtney Brown and Garth Paine stands out as one of the few works that emphasises rhythmic interaction over forms of HCI such as gesture or touch. In their work the rhythmic movements of the dancers generates the tempo of the music, a form of rhythmic interaction that is often referred to as

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99 Tim Ingold, '`Tools for the Hand, Language for the Face': An Appreciation of Leroi-Gourhan's Gesture and Speech', *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 30, no. 4 (December 1999): 411–53, https://doi.org/10.1016/S1369-8486(99)00022-9.
100 Amy Alexander, *Percussive Image Gestural System (PIGS)*, 2018, Multimedia, 2018, http://amy-alexander.com/pigs.
101 Enrique Hurtado, Thor Magnusson, and Josu Rekalde, 'Digitizing the Txalaparta: Computer-Based Study of a Traditional Practice', *Computer Music Journal* 43, no. 2–3 (June 2020): 125–41, https://doi.org/10.1162/comj_a_00522.
102 *New Directions in Music and Human-Computer Interaction* (New York, NY: Springer Berlin Heidelberg, 2019).

“automatic music accompaniment”.

From my own experience, rhythmic processes can be too readily handed over to machines. This is not surprising, as one thing machines excel at is keeping steady time. The philosopher Bernard Stiegler, often an outspoken critic of mechanised music, wrote that “technical inventions are naturalised by man as the operations carried out by the human body are delegated to machines and technologies”.[103] This statement could be read as an extension of Marx’s critique of mechanisation, in which he argued that through mechanisation workers became alienated from the production processes.[104] There could be a case for extending this argument of alienation through to the production of contemporary music which is increasingly created through quantized samples and synthesisers, and the reconfiguring of pre-sets. However, such an argument would need to account for the socially transformative power of electronic dance music, as put forward by artist Jeremy Deller,[105] and the recent resurgence of highly skilled instrumentalists.[106]

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[103] Bernard Stiegler, Bernard Stiegler, and Bernard Stiegler, *Symbolic Misery: Volume 2: The Katastrophē of the Sensible* (Cambridge, UK ; Malden, MA: Polity Press, 2015). 7.

[104] Karl Marx, Ben Fowkes, and David Fernbach, *Capital: A Critique of Political Economy*, V. 1: Penguin Classics (London ; New York, N.Y: Penguin Books in association with New Left Review, 1981).

[105] ‘Jeremy Deller on Raving: “Stormzy and Dave Give Me Hope”’, https://www.theguardian.com/music/2019/aug/09/jeremy-deller-on-raving-stormzy-and-dave-give-me-hope.

[106] ‘The British Jazz Explosion: Meet the Musicians Rewriting the Rulebook’, https://www.theguardian.com/music/2018/apr/08/british-jazz-invasion-moses-boyd-matthew-halsall-nubya-garcia.

The metronome, click track and beyond

Both the metronome and the more recent click track are clear examples of how machines have dominated musical time. From Galileo Galilei's experiments with pendulums in the seventeenth century to Dietrich Nikolaus Winkel's 1814 musical 'chronometer', there is a long history of mechanical devices for keeping time. However, it is widely accepted that it was the German inventor Johann Nepomuk Mälzel who finally popularised the metronome in Europe and America. The impact of this invention on the performance of music is documented in Alexander Evan Bonus' PhD thesis, *The metronomic performance practice: a history of rhythm, metronomes and mechanization of musicality*.[107] Here Bonus highlights the large amount of time it took for the device to be taken seriously. At the time of its 1815 patent, the metronome was championed by a few composers such as Beethoven, but otherwise widely perceived as a novelty. From our current perspective it is hard to imagine a time when the objective pulse of a metronome was considered deeply problematic. As Bonus writes, "a culture increasingly reliant on machines and mechanical data for the teaching, composing, and performing of music, this metronomic turn is barely recognized as having occurred at all."

The click track is a further development of the metronome, allowing the click to be connected to audio-visual recording processes. It was first developed to synchronise sound to picture by "punching holes along the edge of a film",[108] and is now ubiquitous in popular music. This is elegantly demonstrated in Paul Lamere's BPM plots that clearly show how

[107] Alexander Evan Bonus, 'The Metronomic Performance Practice: A History of Rhythm, Metronomes, and the Mechanization of Musicality' (Case Western Reserve University, 2010).
[108] George Burt, *The Art of Film Music: Special Emphasis on Hugo Friedhofer, Alex North, David Raksin, Leonard Rosenman*, Nachdr. (Boston, Mass: Northeastern Univ. Press, 1995). 64.

many modern pop songs are synchronised to click tracks.[109] Practicing and recording to a click has also made its mark on forms of music such as flamenco. Whilst analysing a 1950s Solea and trying to understand the stretching of the rhythms, the guitarist Jose Manuel Leon laughed and said to me, "[they] didn't have Pro Tools or Logic back then, they just played how they felt".[110]

From rhythm orientated laptop music to mechanical music, it is now common for computers or machines to keep control of the tempo and for performers to manipulate events that unfold in time. A key thing I learnt through studying Batá drumming was a deep appreciation of playing music that could fall apart at any given moment. Weekly lessons explored controlling subtle shifts in energy and the interdependence required to keep the music flowing. As my research developed, I aimed to incorporate these elements into the works. This was not always achievable for reasons discussed below but it became more and more of a preoccupation.

Within the micro-temporal world of data communications, click tracks are called clocks. These are regular pulses created by an oscillating voltage. Serial data, for example, is defined as being synchronous and uses two channels, one for a clock and one for data. Asynchronous connections work without a clock, whereby data can be transferred on one channel but relies on a start bit and stop bit to frame the data. This is best understood through the following diagram.

[109] Lamere Paul, 'Revisiting the Click Track', *Revisiting the Click Track* (blog), https://musicmachinery.com/2010/02/08/revisiting-the-click-track/.
[110] Jose Manuel Leon, private guitar lesson, 22 September 2020.

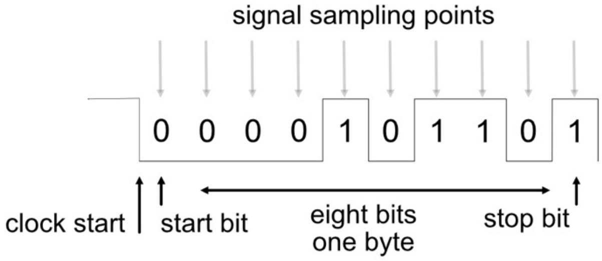

Figure 16 Diagram of an asynchronous signal

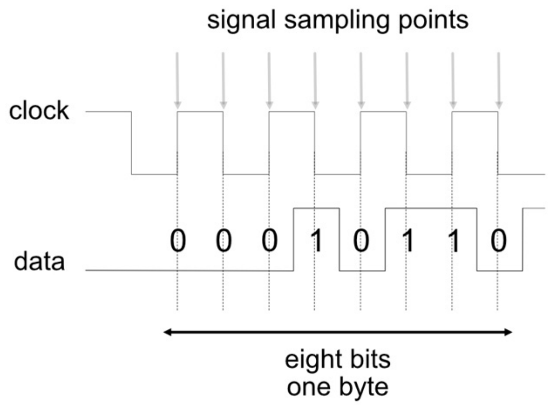

Figure 17 Diagram of a synchronous signal

In my first implementation of the software used in *How we communicate*, I recreated an asynchronous serial port as faithfully as possible. In practice this meant that the performer and machine had to work to the same tempo, but the computer's click track was silent. To achieve synchronisation, the performer had to sing a continual note to prepare the software to listen for data. As soon as the singer stopped, the computer would start listening for information. As this is difficult to describe in words, the process can be best understood through the following diagram and the video documentation in the portfolio.

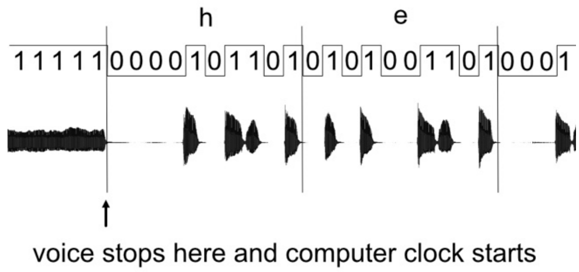

Figure 18 Plot of Tamsin Mendelsohn singing hello in binary

Whilst this technique worked, it proved to be very difficult to use as the performer needed to precisely control stopping the note. This was not helped by the fact that sounds always have a decay to them, which makes the end point of a sound ambiguous. For this system, the performer also had work to exactly the same tempo as the computer, thus creating another area that could go wrong.

In *Clapping ASCII*, I again purposefully tried to keep the click track external from the software. This used a different approach, whereby I wrote the software in such a way that each byte of information needed to be framed by two clicks. This meant that the byte of information could be sent at any rate. Within the installations this was guided by a metronome but could also be used without, allowing audiences to test their timing.

Copying Clave also explored another asynchronous form of interaction. In this work, I developed software to listen to onsets from a pair of claves. When a rhythmic phrase was repeated consistently, the computer began to copy it and play back a software version. In a poster presentation at SMC, I proposed that this algorithm could be improved upon and become a Turing Test for rhythm. Interestingly, during the conference only one person, who happened to be a passing young musician, was able to play a repeated pattern consistently enough for the computer to copy it.

Whilst the above two configurations revealed the concept of asynchronous communication within computing and provided some interesting forms of interaction, they were very difficult to use. However, they did closely resemble how rhythm was taught to me in Batá lessons with Dr Christian Weaver. Often, we (students) would be given a simple rhythm to play on either the Okonkolo or Itotole, and he would try to throw us off by playing against us. This would range from complex syncopations, cross rhythms to seemingly completely random hits. The concept here is that players need to develop the ability to ignore external sounds and maintain a rhythm. This allows the lead drummer or Iya player to play across the rhythm in such a way that it creates confusion and disorientation and has the ability to "subvert reality"[111]. In *Live coding a cajón* I tried to recreate this experience by using ASCII characters to trigger rhythmic loops in Ableton. Simple loops followed the beat and acted like a click track, and more complex ones challenged me to keep time. This provided interest but ultimately, I was in charge of what rhythms were to be generated and therefore never surprised and the computer dominated the tempo so the music did not have the fragility I was seeking.

In other pieces a click track was used as it was much more reliable way of producing text. This was the case in *Duplex Drumming* where both professional percussionists were so comfortable playing to click tracks, that to try anything else risked not producing the ASCII characters. A click track was played through in ear monitors, this tempo was controlled via

[111] Subverting reality is a term that was frequently used in the Batá classes I attended with Dr Christian Weaver to describe the powerful effect polyrhythms can have on listeners.

software from a laptop. During the performance the percussionists worked through three sections of the piece that moved from 120 BPM to 140 BPM to 180 BPM.

The work that allowed for the closest experience to playing fragile polyrhythmic music such as Batá and Comparsa was *Parallel Voices*. Here I made the decision to remove the computer click track entirely and to drive the rhythm throughout the performance by hitting either claves or a drum pad. The state of the bits was evaluated on the impulse of a hit trigger. This was effective both live and in rehearsals as it allowed us to have complete control over the tempo and allow the piece to gradually speed up, or practice things very slowly. It afforded a form of rhythmic entrainment where the tempo would emerge from the dynamic group who "become synchronized by virtue of interacting with each other".[112] The changes in tempo from section to section were inspired by studying Batá and Cuban Carnival music which both have a tendency to build energy by shifts in tempo. Here I would like to suggest that there should be more research into ways to use harness this collective energy within the field of musical HCI, for both its effect on audiences and documented benefits to health and well-being.[113]

[112] W. J. Trost, C. Labbé, and D. Grandjean, 'Rhythmic Entrainment as a Musical Affect Induction Mechanism', *Neuropsychologia* 96 (February 2017): 96–110, https://doi.org/10.1016/j.neuropsychologia.2017.01.004.
[113] J. Trost, Labbé, and Grandjean.

The search for musicality in serial data

As discussed in Chapter three, *listening to code,* the ten bits of information in serial communication were translated into a musical context by conceiving of them as a group of ten notes or rests. To make them easier to notate and play I subdivided them into quavers in a bar of 5/4 as shown.

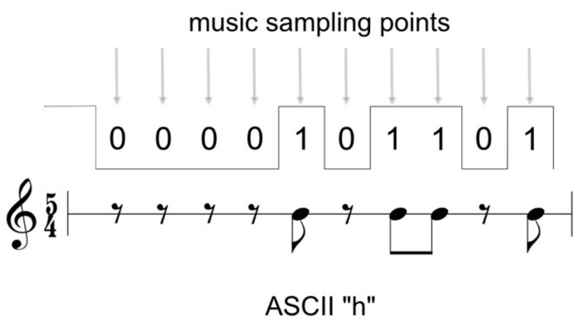

Figure 19 Rhythmic notation of the ASCII letter h

ASCII in this structure has a particular rhythmic form. Each ten bits of information always begin with a start bit of zero and ends with a one, and the seventh and eighth bits are always one. Whilst trying to get used to performing these ASCII letters I found it useful to become very familiarised with this rhythmic motif as it is repeated in every lower-case character.

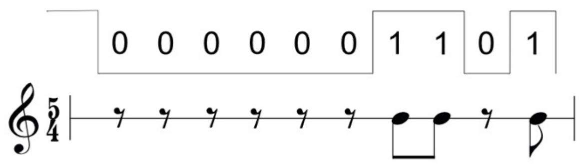

Figure 20 Rhythmic motif of ASCII

Having this basic lower-case template 'internalised' allows one to concentrate on typing letters with rhythm. As the Latin alphabet is 26 letters long, the player only needs to manipulate 5 bits as can be seen in the following diagram.

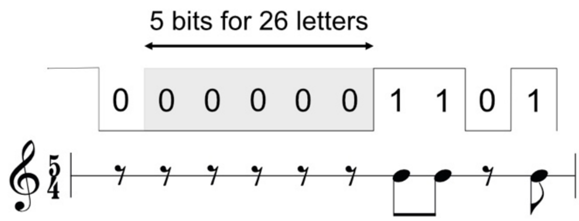

Figure 21 The five bits to manipulate to change lower case letters

If this is considered a rhythmic template for lower case ASCII, a small change in the rhythm can be used to create upper case ASCII.

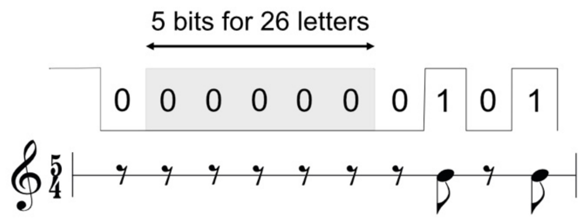

Figure 22 Rhythmic motif of ASCII upper case letters

The same logic can be applied to working with numbers and special characters. In mathematical terms we are simply taking away 32 to move between 97 to 122 (lower case) and 65 to 90 (upper case). In terms of improvisation this shift has interesting properties because the slight change in feel in the rhythmic template allows us to switch between upper case, lower case or numbers. I explored this effect in Duplex Drumming where simultaneously one drummer wrote "abcdefgh" and the other drummer wrote "1234567". The slight offset between the rhythms created a rhythmic tension between the two drummers.

Figure 23 Fragment of Duplex Drumming score

Both flamenco and Afro-Cuban music share similarly highly evolved rhythmic frameworks to transmit musical information. These frameworks are created through accented beats within a cycle. Flamenco artists refer to this as this compás and Afro-Cuban artists as clave. These rhythmic templates are often absorbed from childhood and become internalised by players to the point where the patterns can be completely present in the music but barely played. A good example of this can be found in Cuban Batá music, where the clave is rarely played directly on an instrument, but its form can be heard in the singing and the drumming and can be considered the key to the music. The continual historic use of these rhythmic forms account for the vast number of permutations and possibilities that they afford. For example, the 6/8 clave used in many styles of music in Cuba has the ability to be subdivided in a huge amount of ways, allowing the creation of endless rhythmic variations.

Having undertaken the technical task of being able to play binary rhythms that produced ASCII characters, I found myself asking the following questions: are the rhythms interesting to play or listen to? Can they groove? These are perhaps ridiculous questions, but from my experience of developing the work alongside flamenco and Batá, there needs to be physical and embodied enjoyment in playing the rhythms for the player to want to put the time in to study them.

Ethnomusicologist Harris Berger provides a useful definition of the word groove as "a pattern of accents and timbres that is layered on top of the time signature."[114] I first exploited this in *How we communicate* where down beats were emphasised by the sound vocal sounds of Ta and Ka to emphasise downbeats and upbeats. These vocalisations of rhythm were directly taken from a system of called Konankol.

As I continued to work with 5/4 binary patterns in *Cryptoguitar,* I considered how the rhythms could become more interesting to play. For example, I found that tapping my foot every four beats gave the music a better sense of flow and, to use Ihde's terminology, stronger embodied relations with both the guitar and my ability to create text with the custom interface. I noticed a shift from thinking about the rhythm to it feeling embodied. The even rhythmic pulse gave momentum to the music and also rhythmically displaced the repeated pattern making it much more enjoyable to study and play.

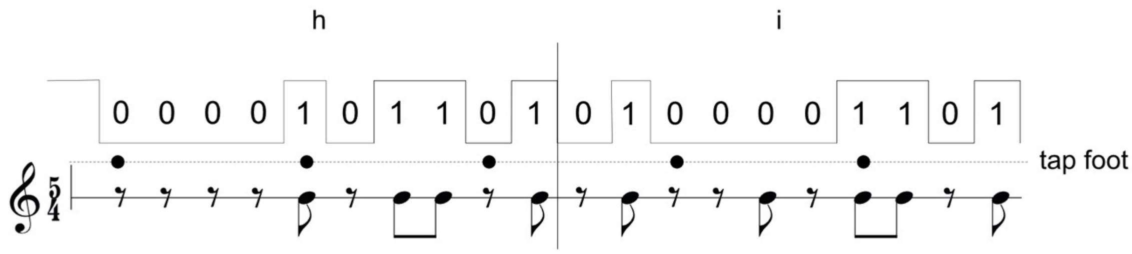

Figure 24 Notation for word hi with foot tapped every two beats

[114] Harris M. Berger, *Metal, Rock, and Jazz: Perception and the Phenomenology of Musical Experience*, Music/Culture (Hanover, NH: University Press of New England, 1999). 97.

During my musical studies I found it was rare to attempt to play syncopated rhythms without an embodied reference to a regular beat. When flamenco guitar this could be marked by a foot, a brush of a finger or a golpe (tap) or even quiet vocal sound. Cuban Batá players make frequent use of apoyos (silent touches on the drum) to mark beats. These subtle markers add to the groove and character of the music and for me mark a significant difference between playing rhythms and generating them on a computer.

Techniques such as feeling an even pulse across accents is very common in modern flamenco guitar and can be seen in this transcription of a typical Buleria falsetta. Here I have notated the phasing of the music, the compás and also where the foot is often tapped to feel the groove. What can be interpreted as very fast music is grounded by a foot tapped at walking speed.

Alongside exploring how to tap the foot to these ASCII patterns, I also explored displacement techniques used in flamenco guitar, such as placing bass notes that are expected on down beat on an upbeat. Although these explorations of groove appear idiosyncratic, they dramatically increased the musical interest in the patterns. The desire to push the constraints of these binary patterns was also my experience with other percussionists. After initially grasping the concept, they would very quickly begin adding embellishments to create more rhythmic interest.

The search for musicality in parallel data

Parallel Voices, based on parallel data communication, involved eight performers, and aimed to be accessible to people with a range of musical abilities. As the software was designed to produce one character from each pulse, or each combination of zeros and ones, there was no time signature. I made the decision to score words using the "tubs system" which is credited to the musicologist Philip Harland and had been in use in Korea for hundreds of years.[115] This allowed each person to see their part in relation to the rest of the group.

In practicing the piece, however, we quickly discovered that it was useful to impose a time signature on it so that we could orientate ourselves. Here is an example of a score for the word breath. The word is 6 characters long, but in rehearsals we added two spaces to make it 8 beats long. This made the word much easier to learn and repeat.

[115] Toussaint, *The Geometry of Musical Rhythm*.

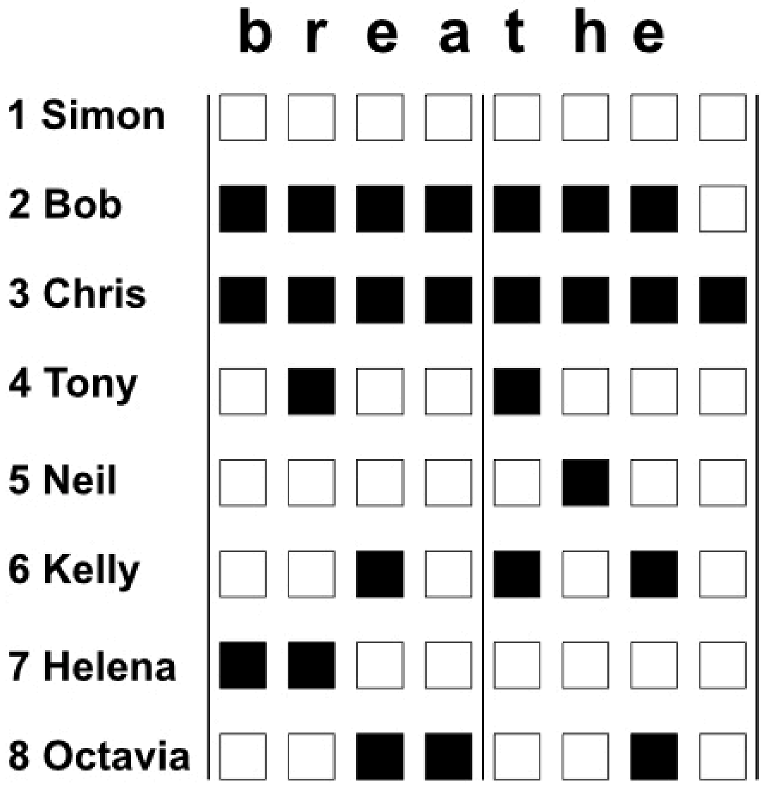

Figure 25 Parallel Voices score example

In this example, Helena would sing on the first two beats of bar one and Simon would be silent throughout. Similar to the previous serial data example, it was possible to change between lower and upper case by Chris either singing or remaining silent. To produce longer cycles of text would require some practice and dedication from a group and I hope to get the opportunity to explore this further. Possible examples of what could be achieved with the system of this can be seen and heard in the software simulations presented in the portfolio.

Conclusion

Developing ways to rhythmically interact with computers beyond using click tracks played an important part of this research. I sought to incorporate the fragile and demanding nature of playing live polyrhythmic music into the works. These experiments sometimes had to be sacrificed in order to create performable works and working to a click track was often the most reliable way of doing things. Studying artforms such as Batá and flamenco provided rich ways to approach how the binary rhythmic patterns could be interpreted. Being forced to play the rhythms with the body added new dimensions to playing data that are distinctly different to computer based sonifications. This finding is echoed in research by Alexandra Supper who uses the term "data karaoke" to describe the use of body skills to present data, she states;

> "data karaoke does not engage the sensory organ of the ear alone; rather, it is a multisensory skill, involving the senses of hearing, seeing and touching, and the whole body of the person engaging in data karaoke as well as of the audience."[116]

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[116] Alexandra Supper, 'Data Karaoke: Sensory and Bodily Skills in Conference Presentations', *Science as Culture* 24, no. 4 (2 October 2015): 436–57, https://doi.org/10.1080/09505431.2015.1052390.

Chapter 6: Playing code

This chapter explores the creative potential of using embodied actions to play symbolic codes as a means of musical HCI. It considers what the processes of creating computer legible symbols can offer as form of music interaction beyond the conceptual premise of revealing the rhythmic patterns of data and its transformation into text, colour and image. Through examples of my work, I argue that there are many rich directions to explore, including using the patterns as a form of composition restraint, producing rhythmic poetry and livecoding.

Reliable technology

Before discussing the ability of performers to *play code* I would like to start by stressing the importance of developing systems that are able to work quickly and responsively. I found that any system needs allow the performer to concentrate on the process of creating symbols, rather than having any doubt about whether the interface itself is working properly. Performers need to be assured that errors are their fault and not the fault of the technology. This is a somewhat obvious point, but my experience of working with musicians whose main focus is rhythm was that the slightest lack of responsiveness made it very easy to dismiss the software or hardware and indeed the entire concept.

The serial translator circuit used in many of these works operated in two separate time domains: the real time moment of hitting or touching something and the longer duration of phrase, bar, byte (after x number of hits y happens). Working within both time domains created multiple points where confusion could occur, therefore the interface display was continually developed throughout the research to make it more robust, responsive and legible.

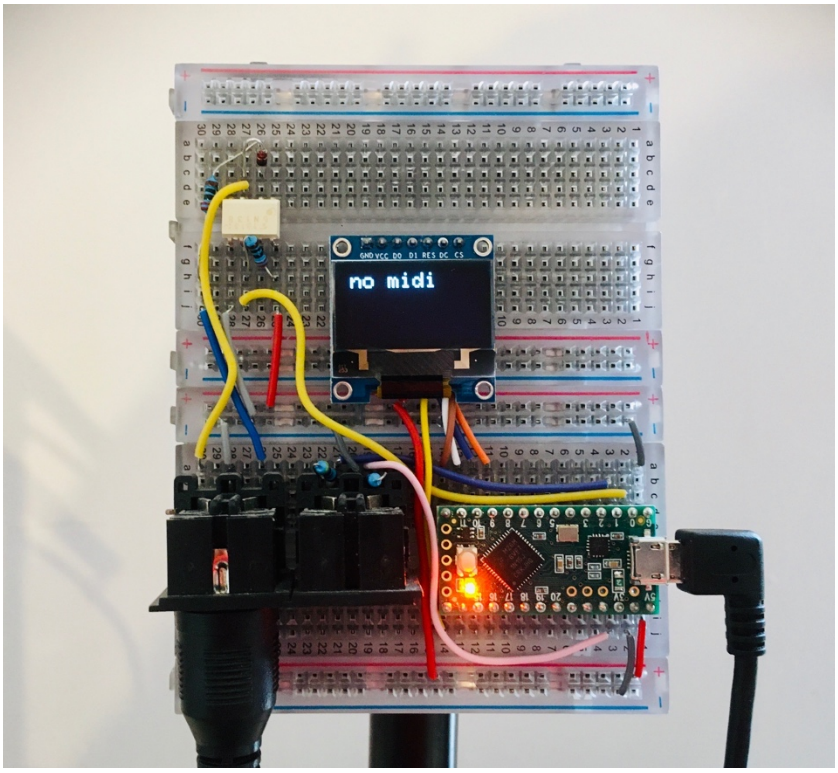

Figure 26 Rhythm to ASCII translator circuit in 2020

The circuit that translated serial rhythm into text and was used for many of the works continually developed throughout the research period and shifted from computer software on a laptop, to software written in OpenFrameworks on a Raspberry pi, to iPhone app, and, eventually, to a standalone device on a Teensy microcontroller. The requirement of digital instruments to be reliable and robust is echoed in research by Sullivan and Wanderly who argue that stability, reliability, robustness and compatibility are key to the longevity and their success of interfaces.[117]

The key developments implemented in the final designs were as follows:

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[117] John Sullivan, 'John Sullivan, Marcelo Wanderley. Stability, Reliability, Compatibility: Reviewing 40 Years of NIME Design.', *McGill University / Université McGill*, 2018, hal-01745984.

- Standalone hardware: performers have different computers, phones and are sometime reluctant to install and configure software. (stability, reliability, robustness)
- The hardware must be fast to turn on and begin using. Here I used a Teensy Microcontroller[118] as it turns on almost immediately, plugs into power source or USB and behaves like keyboard sending letters. (compatibility)
- MicroUSB very common. (compatibility)
- Midi clock input (compatibility, reliability)
- OLed Screen (responsive)

Similar decisions were made in the development of software and hardware for *Parallel Voices*. Whilst this work required the use of more equipment, including microphones, an eight-channel soundcard and laptop, the set-up time was equally important. Rehearsals were often short, so I continually aimed to make the set up quicker and more reliable. Simple processes such as labelling cables and microphones, enabling software functions to be controlled by a midi controller became crucial to setting up quickly and using the system. In this work I also adopted certain industry standards such as using Shure SM58 microphones. This meant that when the work was eventually commissioned and performed, the technicians at the venue also had a clear sense of the technology being used.

Developing ways of capturing the movement of the right-hand fingers for the work *Cryptoguitar* was the most technically demanding and time-consuming work in terms of developing accurate sensing and tracking. The system went through the following iterations.

[118] *Teensy USB Development Board*, 2020, https://www.pjrc.com/teensy/.

- Flamenco Guitar > piezo trigger > onset detection > translator circuit
- Flamenco Guitar > Custom light sensor > Axon100 > translator circuit
- Flamenco Guitar > Custom light sensor > string onset detection > translator circuit
- Flamenco Guitar > Custom light sensor > Fishman Triple play > translator circuit
- Godin Multiac > Fishman Triple play > translator circuit
- Flamenco Guitar > Custom light sensor > Bela > translator circuit

Figure 27 Custom light sensor for Cryptoguitar

Using the Godin Multiac was the most reliable for writing code, but the sound of a truly acoustic instrument was much preferable. Therefore on many occasions I would check the code worked on using the Godin guitar and translator circuit and then practice playing on an acoustic guitar with a metronome or my feet and simply imagine the text appearing. On reflection a guitar an overly complicated instrument for the task of reliably *playing code.* The relationship between musical keyboards, play and computing has a more established history and this is well documented the in the book *Keys to Play*[119] by Robert Moseley. Here Moseley draws links between Émile Baudot's use of a musical keyboard to transmit data and the influence of this on game controllers. I avoided the piano as an interface as I felt that it was already too mechanically mediated. The appeal of the guitar was the direct relationship between touch, strings and sound. With the interface connected, I felt that this extended into the realm of the digital enabling one to have the sensation of literally touching binary digits and watching them transform into ASCII characters.

[119] Roger Moseley, *Keys to Play: Music as a Ludic Medium from Apollo to Nintendo* (Oakland, California: University of California Press, 2016).

Virtuosity or flow

My research began by executing basic codes slowly. Clearly, works such as *How we communicate* have little reference to any notion of virtuosity; however, as I began to develop longer, more complex pieces, such as *Duplex Drumming*, *Parallel Voices* and *Cryptoguitar*, the question of virtuosity demanded more attention. I began to envisage and simulate in software long texts being seamlessly performed, but needed to stop myself to consider if this would be at all possible to perform, and how desirable it is as feature of music. This question of fluency was raised during a conference called *Hybrid Live Coding Interfaces* during which I presented *Cryptoguitar*. Here I was asked:

Do you see this system as something more suited for a specific performance, a single piece (which can be rehearsed and maybe solve the cognitive overload problem), or as an instrument you gain fluency on over a long period of time?

Here my interest is primarily in developing systems that allow for a form of improvisational fluency. From flamenco to Cuban Batá I have made continual reference to works that emphasise the use of building blocks of rhythmic vocabulary that can be combined in infinite ways. In my experience, improvisation in these artforms is often misunderstood as playing freely without constraints when it is actually much more about utilizing fragments of rhythmic vocabulary within very defined rhythmic constraints. The difficulty lies in getting confident enough with the rhythmic vocabulary to improvise with it, finding other players that are willing to learn to play with the same language and, in the case of this research, having reliable technology with which to translate the rhythms.

Parallel Voices was an interesting case here. During the development of this piece, I produced many simulations of texts being recited and polyrhythmic polyphonic sequences that moved through colours. In rehearsals I quickly realised that these would be incredibly difficult to perform and developed simpler solutions, such as repeatedly singing one word rather than sentences. Peer feedback from the Lowry performance suggested that often simplicity is preferable to virtuosic performance and that there can be a stronger connection between the audience and the performers when the audience are able to relate to what is happening.

My research demonstrated that there needs to be a clear relationship between the musician's action and the response from the technology and I would argue that a sense of flow is far more importance than virtuosity. I refer here to the concept of flow as developed by psychologist Mihaly Csikszentmihalyi,[120] which he defines as "a state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself."[121] I found that many of my works, and in particular *Cryptoguitar* and *Parallel Voices* created conditions that were optimal to achieving flow. Here both systems required high levels of concentration on a very narrow field and had clear goals with immediate feedback. There was also a heightened control of one's actions and a satisfaction when everything worked.

Csikszentmihalyi's work focuses mostly on the experience of the subject but I would add that these conditions and states of flow are important to both performers and audiences. Peer feedback on a video of edited works such as *Cryptoguitar* suggested that when everything flowed, the performer is engaged, the technology is working, and the audience stopped thinking about how the work functioned, or whether it's doing the right thing, and became absorbed in the ability of the performer to produce text. However, states of flow are

[120] Csikszentmihalyi, *Finding Flow*.
[121] Schüler, 'Flow Experience and Learning'.

incredibly hard to achieve in live performance. This has been noted by Joann Marie Kirchner who has researched how performance anxiety can impede flow. Kirchner makes the following recommendations for performing with flow which I agree are valuable:

> Being certain that the repertoire does not exceed an individual's skill level prevents boredom and anxiety and allows the individual to be confident in their undertaking. Being immersed in the music helps the performer to remain in the present moment and wards off any task-irrelevant thoughts.[122]

[122] Joann Marie Kirchner, 'Incorporating Flow into Practice and Performance', *Work* 40, no. 3 (2011): 289–96, https://doi.org/10.3233/WOR-2011-1232.

No fun with sinewaves

Of all the works produced, *Clapping a Sinewave* was possibly the least enjoyable to practice, play and perform. In this piece each bar or byte of clapping resulted in the production of one audio sample that was 0.01ms long and continuously looped in a buffer until the creation of a new sample. The trade-off between the amount of effort required to input the binary data and what was produced by the computer here was extreme.

As a sine wave is continually changing, the binary rhythms representing each sample also change every bar. The lack of any repetition in the piece made it difficult to learn and follow. The production of ear-piercing fragments of waveforms was a little unappealing and the piece was more interesting as a conceptual work than a musical one.

Compositional restraints

For me playing the rhythms of ASCII letters with percussion or a guitar became more rewarding than clapping audio signals. Being forced to work with the particular rhythmic constraints of ASCII phrases led me to new explore new rhythmic ideas and challenges. This was particularly true when applied to a tonal instrument such as in *Cryptoguitar*. Here the rhythmic phrasing could be interpreted melodically which created the potential for countless variations. Exploring melodies that fitted the mood of a word or phrase generated new musical ideas that often surprised me, as melodies became mnemonic devices to remember words and phrases. From my perspective as a player there was a magical quality of letters appearing from the discrete musical movements of my fingers. The embodied relation with the instrument and the hermeneutic relation with the code meshed together to create a sense of flow which is certainly challenging, merges action awareness and is defined by clear goals.

A problematic issue with many of the works, and particularly *Cryptoguitar,* was that any sense of flow was easily interrupted by a technical glitch, and there were many stages in the signal path where this could happen. This included rough fingernails, shaky fingers, guitar sensor, cables, midi conversion, software latency and translator circuit, not to mention the demanding physical aspect of playing the instrument, timing, cleanness of notes, fret noise. Any problems were amplified in a performance context where technology is often more likely to go wrong and rhythmic accuracy is impeded by shaking fingers.

When the system was set up well, it functioned like a strict music teacher, immediately highlighting when something was played correctly or incorrectly. However, it also encouraged playing the instrument in a very particular way. This raised the question: is this way of playing desirable? For example, playing notes on a guitar cleanly and with accurate timing is associated with good playing, but often I felt I had to control the dynamics of the playing to service the technology rather than the music. The fact that the system explored both the embodied relations of playing the guitar and the hermeneutic relation of producing text meant that one often had sacrificed for the other.

In most musical performance situations, one would be encouraged to ignore mistakes and continue but an issue with writing code or text is that there can be imperative to get it right. I experienced this directly when performing on *Cryptoguitar* at SMC in Malaga. I had composed phrases to perform that would produce text, however through a combination of nerves and latency issues I kept making typos. Here I had to make the choice of trying to repeat the phrase until I spelt it correctly or quickly move to another simpler part of the performance I had prepared. This starkly revealed the tension that can occur between embodied and hermeneutic interactions. However, after this experience it was clear that I needed to improve latency issues and become more confident with playing the rhythms.

In the piece *Duplex Drumming*, the percussionists also enjoyed the constraints of generating ASCII characters and in particular the potential of incorporating them into more complex rhythms. Interestingly for them, working from a written score, the process of seeing a character appear at the end of the bar became almost irrelevant as they had already moved their attention to the next bar. The ASCII characters became a trail left behind them. My conclusion here is that it can be more rewarding to spend time with musicians learning small amounts of musical and textual vocabulary and to utilise these as much as possible. This was something we did during the performance at Algomech. Here there was a section when each drummer played their rhythmically favourite ASCII character.

The work *Parallel Voices* with its use of multiple performers to produce text, colours and images at a range of different tempos also has great potential for future creative projects that bring together people and computers in ways that puts emphasis on group timing and collaboration. The performance at the Lowry and many software tests demonstrate some possibilities of this work, but there are many more ideas I would love to explore, such as adding signalling for the singers and composing images with 24bits of colour and 24 people, producing longer pieces of text, triggering computational processes through live coding, and working more on complex harmonies.

Content and meaning

To encode semantic information into rhythm and music requires commitment from both the composer and performer and quickly raises questions about the content and meaning of what is produced. It also raises questions of resolution, or, to use Aristotle's term, telos. The work *Clapping a Sinewave* had the resolution of producing a sinewave, the piece had a contained structure that was understood by both performer and audience. However, working with streams of text demanded an answer to the question: To what end do we embed streams of text into music? Studies of the meaning of text encoded in instrumental music have taken place within distinct areas Nigerian Bàtá (Amanda Villepastour)[123], DunDun (Akin Eub)[124], Lokele talking drum[125], (John F. Carrington) Western Traditions of musical cryptograms[126], (Eric Sams) Live coding, (IOhannes m. zmölnig)[127] However, I am not aware of a wide-ranging study that covers all of these diverse motivations for encoding language into instrumental music. In lieu of such a study, then, I will summarise some of the trends.

Nigerian Bàtá - Orisha worship, humour, insults

Dundun - Orisha worship, humour, insults

Lokele talking drum - humour, ceremonies, jokes, games, news

Western classical music - composers' names, religious worship

Messiaen - religious worship

Live coding - technical code legible to those initiated, sometimes humorous comments

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[123] Villepastour, *Ancient Text Messages of the Yorùbá Bàtá Drum*.

[124] Akin Euba, *Yoruba Drumming: The Dùndún Tradition*, Bayreuth African Studies Series 21/22 (Bayreuth, W. Germany: E. Breitinger, Bayreuth University, 1990).

[125] Carrington, *Talking Drums of Africa*.

[126] Eric Sams, 'MUSICAL CRYPTOGRAPHY', *Cryptologia* 3, no. 4 (October 1979): 193–201, https://doi.org/10.1080/0161-117991854052.

[127] IOhannes m. zmölnig, 'Audience Perception of Code', *International Journal of Performance Arts and Digital Media* 12, no. 2 (2 July 2016): 207–12, https://doi.org/10.1080/14794713.2016.1227604.

Religious communication is clearly traditionally a common motivating factor for encoding language into music. This is something that I reflected on from an agnostic perspective. Through the research I gained insights into the powerful rhythms of Orishas and had witnessed how song and rhythm has ability to possess people; alongside this, I was practicing the more prosaic act of writing ASCII through music. It is interesting to note here that connections have been made between information society and religion. In the book *In the Flow*, Boris Groys argues that "Google plays today the role that traditionally was filled by philosophy and religion" and that it "dissolves all discourses by turning them into the word clouds that function as collections of words beyond grammar."[128] My engagement with these metaphysical questions remains highly speculative but points to possible trajectories this work could take. However Afro-Cuban rhythms have developed in such a way that polyrhythms can occur, and these enable such strong reactions. The same cannot be said for data communication rhythms which were not designed with musical relations in mind.

I did not make use of praise poetry and I avoided writing insults. I primarily drew upon philosophical and technical texts I had found inspiring. In *How we communicate* I sung, "hi I am in a signal in noisy channel" in reference to information theory. The repetition of word "Breathe" in *Parallel Voices* was a direct reference to the body and our sharing of air. *Duplex Drumming* took quotes from Gilles Deleuze's essay "Postscript on the Societies of Control "[129] and *Cryptoguitar* used phrases inspired by Lyotard's critique on cybernetics.[130] On reflection these references were perhaps overly oblique, and humour or simplicity could have been used more. Discussions with the performers of both *Duplex Drumming* and *Parallel*

[128] Boris Grojs, *In the Flow*, 2018. 270.
[129] Gilles Deleuze, 'Postscript on the Societies of Control', *October*, Winter 1992.
[130] Jean-François Lyotard, *The Inhuman: Reflections on Time* (Stanford, Calif: Stanford University Press, 1991).

Voices highlighted the issue of the meaning and content of texts. Performers frequently had ideas for what could be written. Clearly this opens up further questions of authorship and has great potential for collaboration and co-authorship.

Live coding

Live coding is the practice of writing and executing computer code to produce audio and visual experiences. It is typically performed live to audiences who are able to see both the performers and the projected code. The links between live coding and this research are clear, but there is also the key difference that, as Click Nelson remarks, "live coding is almost the antithesis of immediate physical musicianship."[131] Although the body is engaged in the physical sense of moving fingers, it predominately emphasises a hermeneutic relation with the technology.

In the work *Live coding a cajón* I began to explore how the ASCII characters that were being generated through physically playing rhythms could be used not just as rhythmic poetry, but that they could also become exploitable and operational, and thus able to generate further computational processes. Each character or combination of characters has the potential to make the computer perform an action that unfolds in time. Whilst this additional layer of mapping and generation of sound created additional confusion, it also became a form of human computer interaction that uses both embodied and hermeneutic relations. I would also suggest that the additional sounds and actions created by the computer could be considered as alterity relations. In other words, the interaction between the machine and performer has the potential go somewhere new and surprising.

Combining embodied, hermeneutic and alterity modes of interaction to a positive effect was a goal I continually pursued but found hard to achieve. I would argue that all of these rela-

[131] Click Nilson, 'Live Coding Practice', in *Proceedings of the 7th International Conference on New Interfaces for Musical Expression - NIME '07* (the 7th international conference, New York, New York: ACM Press, 2007), 112, https://doi.org/10.1145/1279740.1279760.

tions are active while performing art forms such as Cuban Batá and flamenco. As a brief example, in Cuban Batá music drummers clearly engage in playing in an embodied sense but also have to be ready to interpret a rhythmic code or read a dancer's movements (hermeneutic) and then respond. Through this interaction a dancer could become possessed by an Orisha, creating an alterity experience. This is the function, or telos, of the music. I should add here that although I have witnessed such experiences and I am nowhere near competent enough to play in these situations.

In *Live coding a cajón* certain ASCII characters were set up to trigger different loops in Ableton Live. This created a situation which there could be a playful interaction between me playing and the computer producing audio. I found that if the loops were set at different lengths some interesting and surprising musical effects could be achieved. A problem here is that the performer can easily forget the mapping. This is something that happened to me when performing to a small audience at Rogue Artist Studios. In this performance I had set certain ASCII characters to start and stop loops and became stuck because I could not remember the code to turn off the loops.

In their essay "Live Music-Making: A Rich Open Task Requires a Rich Open Interface", Stowell and McLean state that "[a] livecoder, like any improvising performer, is under pressure to do something interesting in the moment" and "can sometimes deny the more raw physiological expressionism that some people seek in music".[132] The form of embodied coding I have described has the potential to make interesting contributions to the field of live

[132] Dan Stowell and Alex McLean, 'Live Music-Making: A Rich Open Task Requires a Rich Open Interface', in *Music and Human- Computer Interaction*, ed. Simon Holland et al., Springer Series on Cultural Computing (Springer, 2013). 146.

coding as it affords embodied coding processes with the potential to produce sound with immediacy.

The challenge is to create languages that are both legible and concise. As I discussed with live coder Alex McLean, there are only so many typos that an audience will put up with. "I think the potential for interesting, accidental feedback loops and interference patterns is large, I guess the trick is how to avoid boring syntax errors".[133]

In *Cryptoguitar* I took the idea of one character per function a little further and experimented with ASCII characters performing operations in SuperCollider such as:

r = record guitar, p = playback sample, q = playback sample quarter speed, h = playback sample half speed, d = playback sample double speed.

Whilst highly confusing to the player and audience, combining creating characters that performed operations whilst playing proved to be engaging, overdubbing different speed sample created alterity relations where there were moments of surprise. Within live coding there is a great tradition of concise coding languages, including Ixi Lang[134] and Brainfuck[135]. Variations of these could be interesting to explore and could be combined with predictive text to avoid syntax errors. However, I would suggest a richer avenue would be found through developing interfaces that begin to translate tonal languages such as Yoruba and Igbo, Akan and Ewe. These languages have already established a strong relationship with music but less so with live coding languages. Here I would turn to research by people such as Túndé Adégbọlá, who has designed Automatic Speech Recognition systems to translate Yoruba

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[133] Alex McLean, 'Private Communication', messenger, 10 December 2019.
[134] Clarke, & International Computer Music Association, 2011
[135] Geoff Cox and Alex McLean, *Speaking Code: Coding as Aesthetic and Political Expression*, Software Studies (Cambridge, Mass: The MIT Press, 2013), 2.

speech to computer legible text and is Executive Director of Alt-i (African Languages Technology Initiative).[136] More work in this area could act as a way of challenging the hegemony of digital culture that prioritises the English language and offer further technodiversity. This form of diversification is similarly discussed by Marije Baalman in an essay paper "Embodiment of code" where she speculates on what live coding would look like if computer architecture had evolved differently.[137]

[136] Villepastour, *Ancient Text Messages of the Yorùbá Bàtá Drum*. 34
[137] Marije Baalman, 'Embodiment of Code', 13 July 2015, https://doi.org/10.5281/ZENODO.18748.

Conclusion

This chapter has reflected on a range of issues that arose from making and playing with interfaces that enable *playing code*. I began by emphasising the need for the interface to be fast and reliable, performers need to be assured that errors are their fault and not the technology. A key finding was that there needs to be a careful trade-off between the rhythm performed and the symbols outputted by a system. Clapping binary patterns to produce individual samples of a sine wave was extreme and a test of an audience's patience. This is in contrast to the system used for *Parallel Voices* where, theoretically, text could be produced faster than speech.

I considered the importance of flow for both the performer and audience and argued for the value of making interfaces that present challenges. I then considered some historic motivations for including text and poetry within instrumental music and points towards directions the work could take. Finally, I argued that live coding, which is currently largely based on hermeneutic relations, could be expanded on by using forms of *playing code* that prioritises embodied relations. From here we could imagine new interfaces that can translate existing tonal drum languages and modifications to live coding languages to interpret the rhythmic codes. This could increase both the technodiversity and embodied relations within this already open and experimental field of music.

Chapter 7: Artworks

Clapping ASCII

http://simonblackmore.net/playingcode/portfolio/clapping_ascii/

Clapping ASCII was an installation where an audience could produce text by clapping binary patterns to a metronome. The binary patterns for the alphabet and basic words were provided as printed scores for the audience to use. Each clapped pattern produced an ASCII character that was displayed on a screen.

Presentation history

Supernormal Festival, Braziers Park, Oxfordshire 2016

Hear East, Queen Elizabeth Olympic Park, London 2016

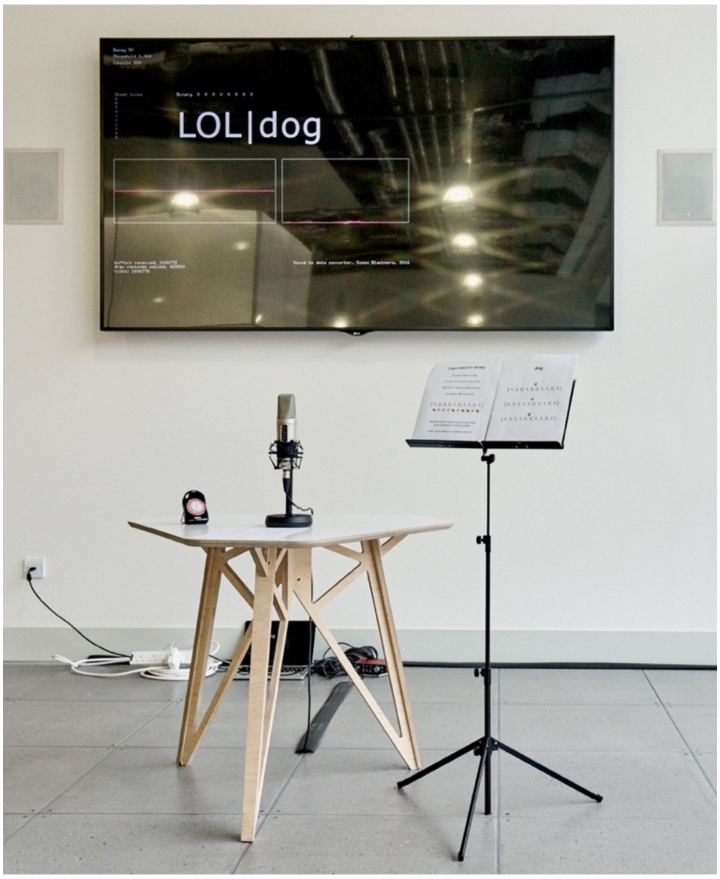

Figure 28 Clapping ASCII, Here East 2016

Background

The aim of this piece was to create a simple but rhythmically demanding interactive system where people could create text on a screen by clapping binary patterns. I was interested in presenting an installation that was both accessible but also some challenge to it.

System design

To realise the piece, I developed software that interpreted how an asynchronous serial port connection works. A microphone was connected to a Raspberry Pi using Focusrite Scarlett Solo USB Audio Interface. I wrote software in OpenFrameworks to detect peaks in the audio. If the amplitude of a signal reached a predefined amount the time was stored in an array. If there were no peaks detected after a certain amount of time, the software calculated the time between the claps to create a letter. This asynchronous system allowed participants to change the tempo on the metronome or even have a go without the metronome.

Scores

To make this work as accessible as possible I used written instructions and notated the rhythms using zeros and ones.

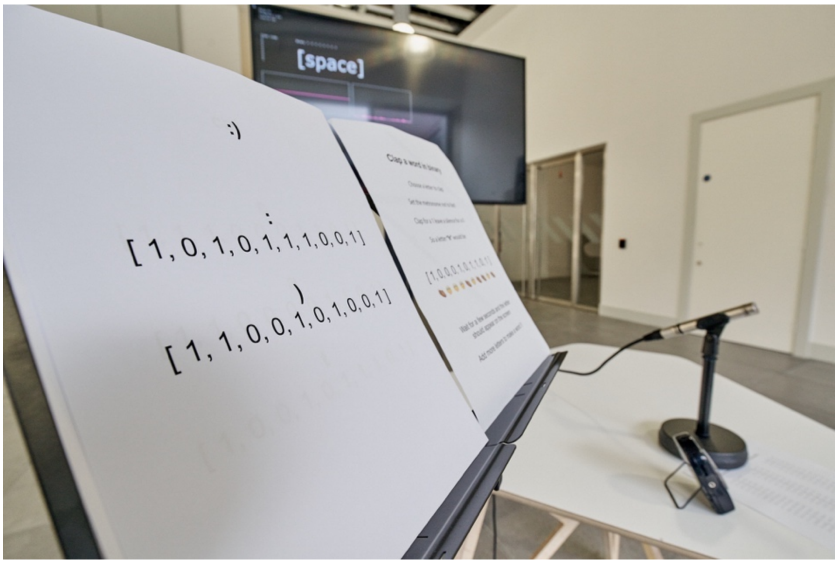

Figure 29 Clapping ASCI score, Here East 2016

Clapping a sinewave

http://simonblackmore.net/playingcode/portfolio/clapping_a_sinewave/

A performance where the binary representation of a sinewave was clapped out and translated by computer software into an audible sound wave. The audience witnessed both the sound of the clapping and the live audio and visual rendering of a sine wave presented on an oscilloscope.

Presentation history

Algomech, Sheffield, November 2016

DIEM Elektro, Det Jyske Musikkonservatorium, Aarhaus, Denmark September 2017

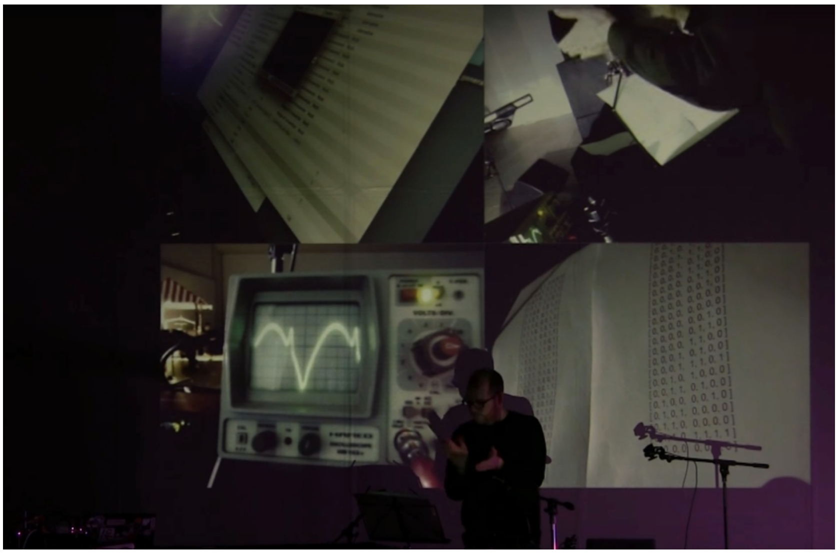

Figure 30 Clapping a sinewave, Algomech 2016

Background

I began working on the piece *Clapping a sinewave* in late 2016. It was initially proposed and accepted as a performance at Algomech Festival, Sheffield, 2016. My previous installation, *Clapping ASCII*, had highlighted the issue that when repeated ASCII binary patterns are clapped, they can become overly repetitive. Once the concept is grasped there is little surprise or resolution, rather an endless stream of claps producing characters.

I chose a sine wave as the basis of the piece as it is an archetypal analogue signal which can never be completely accurately represented by digital sampling because there will always be "a loss of information known as quantisation error"[138] due to analogue to digital conversion. This is easier to show in an image rather than a word.

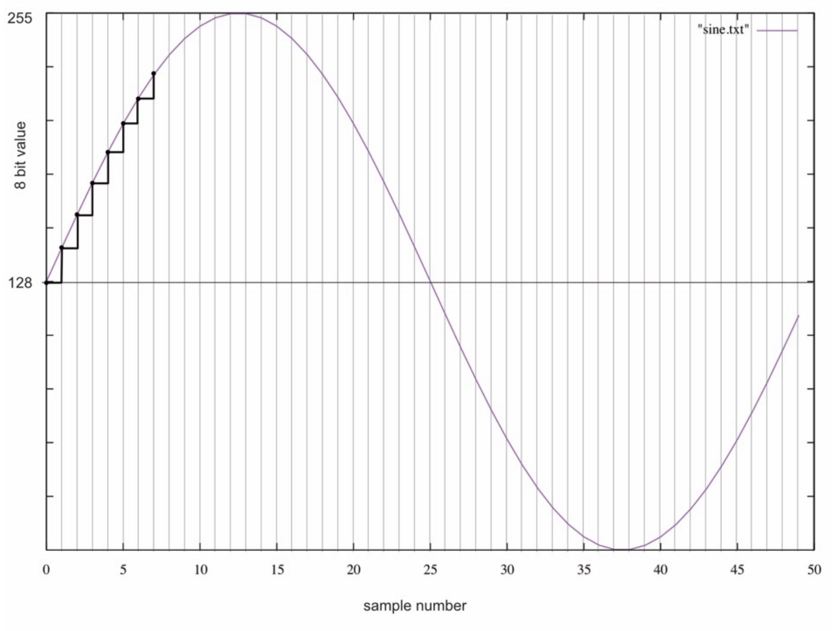

Figure 31 Digitising a sinewave

System design

I chose an eight bit sinewave. This had fifty samples and I could be clapped in 4-5 minutes. The code to generate the wave form was developed following instruction from an example in *The Audio Programming Book* by Richard Boulanger and Richard Lazzarini. I wrote some software in SuperCollider to detect the onsets of a series of claps 1s and silences as 0s. This

[138] Boulanger, & Lazzarini, 2011

was done to a click track, where the first beat of every 4 pules was played as an audible click. At the end of each cycle of 8 bits, SuperCollider produced the appropriate values and entered these into an audio buffer that was played back to the audience as sound.

How we communicate

http://simonblackmore.net/playingcode/portfolio/how_we_communicate_performance/
http://simonblackmore.net/playingcode/portfolio/how_we_communicate_installation/

How we communicate was a performance and installation in which I used my voice to produce binary rhythms to create the following stream of ASCII text. "Hello I am a signal in a noisy channel"

Presentation History

DIEM Elektro, Det Jyske Musikkonservatorium, Aarhaus, Denmark, September 2017 (performance)

Sound & Music Computing Conference, Cyprus, July 2018 (poster)

Audiograft, Oxford, March 2018 (installation)

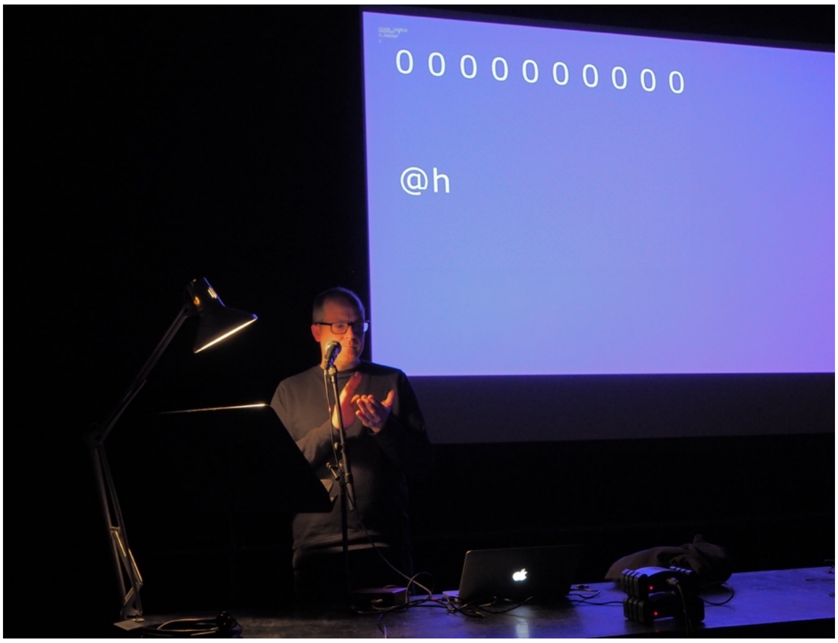

Figure 32 How we communicate, DIEM 2017

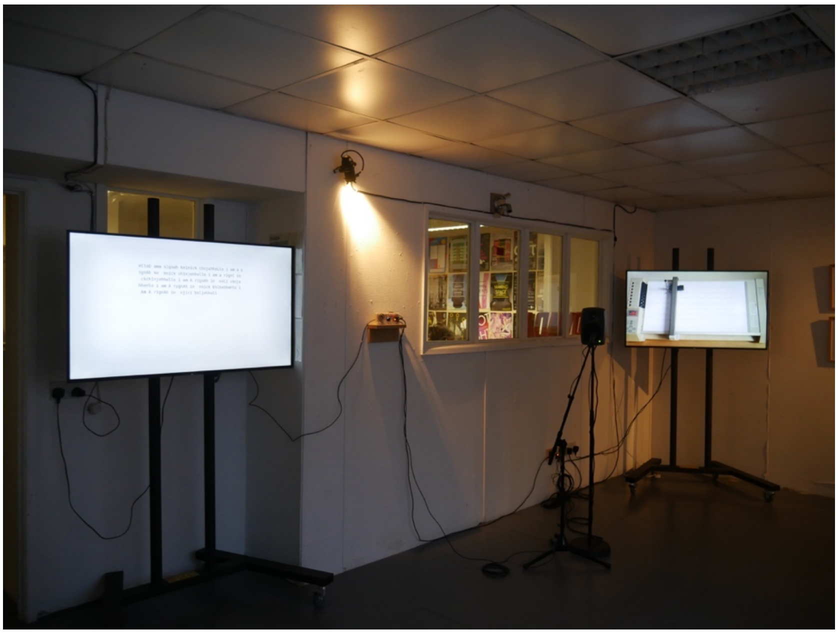

Figure 33 How we communicate, Audiograft installation 2018

Background

The aim of this work was to realise a piece that needed little description. In its performance I purposefully did not say what I was going to do so that the audience witnessed the process of translation and were put in a position to unravel what was going on. The installation was a multimodal experience and included multiple screens, speakers, microphone, custom electronics and plotted drawings that illustrated the relationship between amplitude waveforms, binary code and ASCII characters.

System design

The performance version of this work used software I developed in OpenFrameworks to mimic a serial connection. To avoid the use of additional libraries I used a simple RMS amplitude detection algorithm. I performed the work to an audible click track. In January 2018 I migrated this code to a Teensy microcontroller to try and resolve some issues I had with latency within OpenFrameworks and to work towards making multiple versions that could be used with percussionists.

Live coding a cajón

http://simonblackmore.net/playingcode/portfolio/live_coding_a_cajon/

In this work serial binary rhythms were drummed on a peruvian cajón. These rhythmic patterns are converted into ASCII characters which then triggered loops in Ableton Live. The audience witnessed the sound of the percussive programming and the computers responses. A visual interpretation of the rhythms and letters being coded were provided by a camera displaying a live feed of the rhythm to data translator circuit.

Presentation History

Livecode Festival #2, Sheffield, September 2018

Rogue Artist Studios, Manchester, September 2018

Sonic Interactions, Capstone Theatre, Liverpool, October 2018

Figure 34 Live coding a cajón at Rogue Studios 2018

Background

After exploring using binary patterns to write text I had been considering how these patterns could be used to perform live computer music. I wanted to use a simple instrument so decided on a Peruvian cajón. I had been inspired by a technique of playing the cajón called mano a mano (hand to hand) that had been taught to me in Spain. Here the hands play alternate ghost notes (practically silent) left, right, left, right, etc and notes are accented to create rhythms. This simple technique allows one to both keep a steady rhythm and keep track of where you are in the cycle.

Cryptoguitar

http://simonblackmore.net/playingcode/portfolio/cryptoguitar/

Cryptoguitar consisted of live and recorded guitar music where the rhythmic plucking of guitar strings executed binary patterns that produced both music and ASCII codes.

Presentation history

Sound & Music Computing Conference, Malaga, June 2019 (performance)

Rogue Artist Studios, Manchester, September 2019 (installation)

Hybrid Live Coding Interfaces, online conference, July 2020 (presentation)

Figure 35 Cryptoguitar, Rogue Artist Studios, 2019

Background

The previous works *How we communicate* and *Live coding a cajón* explored the rhythmic properties of binary serial patterns with the voice and hands. Having gained some familiarity with the rhythmic phrases required to produce ASCII text I became interested in how the rhythms could be applied to pitched instruments to add melodic interest to the music. From the perspective of the player, this approach took two directions:

1. To act as a form of rhythmic constraint to compose within.
2. To offer a possible musical approach to live coding, in which each letter or combination of letters can execute computer processes, creating a musical call and response relationship between player and computer.

Through live performances and video documentation audiences experienced a musification of the rhythms of data alongside its transformation into text. The work was influenced by studying flamenco guitar with contemporary guitarists such as Jose Manuel Leon. Flamenco music and dance is underpinned by distinct rhythmic cycles that create a coded language for singers, guitarists, dancers and percussionist to play within. They act as constraints to compose and improvise within. In *Cryptoguitar* I set myself the task of composing within the constraints of binary patterns.

Duplex Drumming

http://simonblackmore.net/playingcode/portfolio/duplex_drumming/

Duplex drumming was a performance piece for two kit drummers, electronics, and two live projections. Two serial connections were recreated to work with MIDI triggers allowing the two performers to play rhythms that were translated into text. The percussionists performed a 15 minute piece that explored conversation in both a rhythmical and textual sense.

Presentation history

Algomech Festival, Sheffield, May 2019

Performed by Sophie Hastings and Jan Bradley from the contemporary percussion quartet 4-Mality.

Figure 36 Duplex Drumming, Algomech 2019

Background

This work was development from the piece *Live coding a cajón* which used a very similar technical set up. Having two professional percussionists play the piece enabled me to create a scored piece that could be repeated and refined. The change in my role from performer to composer enabled me to spend more time considering the overall structure of the piece.

Developing the scores

The work was developed over one initial meeting and two rehearsals. After our first meeting it was clear that the percussionists would need to work from written scores. I scored out a few bars in a notation software called GuitarPro and then quickly realised that converting text into music notation was going to be prohibitively slow using this method. I then worked with a combination of SuperCollider and a music engraving program called Lilly-pond which allowed me to generate the scores efficiently. Examples of these files are available on the portfolio website.

Parallel Voices

http://simonblackmore.net/playingcode/portfolio/parallel_voices/

Parallel voices was a performance for 8 vocalists and a single channel projection. I recreated an 8-bit computer parallel bus software, each bit or bus input was controlled by the amplitude of eight singers voices. The work was realised as a performance at the Lowry, Salford. The audience witnessed a live vocal piece alongside the transformation of voice into data, ASCII text, Colours and bitmaps. This visual information was projected behind the vocalists on a large screen.

Presentation history

Drift at the Lowry, Salford, November 2019

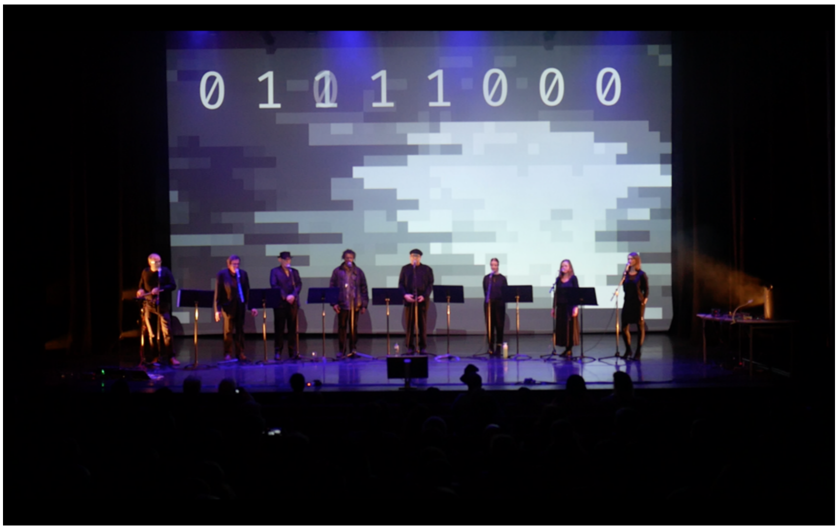

Figure 37 Parallel Voices at the Lowry 2019

Background

The piece developed after reflecting on the slow repetitive process of inputting rhythms as serial data, as a series of zeros and ones. I considered how the transfer of information could be either sped up or made more musical to engage audiences further.

System Design

Within 8-bit parallel data transmission, eight data bits are transmitted over multiple channels at the same time. To recreate this through sound, eight Shure SM58 microphones were connected to a computer audio interface. A software patch developed in Pure Data took the amplitude of each audio input and gated it to either a 1 or 0. The state of the bits (voices) could be evaluated at any time by tapping a piezo trigger. This was attached to a clave and drum pad for varying musical effect during the performance.

When the Pure Data patch was triggered, the byte (a value between 1 and 256) was sent using Open Sound Control messaging to another piece of software written in OpenFrameworks and running on a Raspberry Pi. A tag accompanied each byte and determined whether the visual software produced an ASCII character, colour or coloured pixel. This could be changed by a midi controller. The decoupling of the audio and visual aspects of the work helped to minimise any interference to audio signals from visual, to spread processing power across computers, and to enable the running simulations of the singers in SuperCollider and test the results in the same visual software.

Structure of the performance

The work was made up of eight sections that were developed during 4 rehearsals. Section one established the relationship between the singers' voices and the projected image. Each singer took it in turn to sing into a microphone. This corresponded with a visual representation of a bit projected above their head. The bit changed from one to zero to one depending on the amplitude of their voice. In section two clave was tapped and the data was processed into ASCII characters. At first these letters were random but as the singers started to work from a score we repeated the word breathe, sometimes getting it right and sometimes getting it wrong.

In section three we produced full screen 3Bit colour with the 3 singers located on stage left. With 3Bits it is possible to produce the following 8 colours: 000 = black, 001 = blue, 010 = green, 011 = cyan, 100 = red, 101 = magenta, 110 = yellow, 111 = white. In section four we produced large pixels first using the same 3bits. Here the singers sang a particular pattern to work through the colours in order to produce the following test stripes. In section six we produced bars in shades of grey by allowing the singers to sing whenever they wanted. For the seventh section we created a low resolution image of a cloud. The work ended with all possible modes turned activated creating a glitchy image.

Developing the scores

The piece was intended to be performed by a group and to be accessible to people with a range of musical abilities, so a grid system was used allowing each vocalist to see their part in relation to the others and broken into 4/4 time.

Copying Clave

http://simonblackmore.net/playingcode/portfolio/copying_clave/

In this work computer software listened for a repeated pattern and then attempted to play along with the it. It was envisaged that such a system could be used for musical education purposes, music practicing and live interactive music. It was presented with the idea that others could write similar software and that this could act as blindfold Turing test.

Presentation history

Sound & Music Computing Conference, Malaga, June 2019 (poster)

Background

During Afro-Cuban music classes a teacher would often play a repeated clave pattern and I would be asked to listen, sing it and then play along. I began to wonder how this process could be implemented on a computer. I came up with a moderately successful solution which I presented at SMC. Only a few participants were able to play a repeated pattern precisely enough for my implementation of the software to copy them.

Figure 38 Copying clave, a successful participant at SMC 2019

Chapter 8: Conclusion

This reflective commentary has traced the development of hardware, software, and performance strategies used to address the following two questions: How can computer signals be deconstructed and reconstructed in the form of embodied sound and music to develop performances and installations, and what new encounters in the field of interactive computer art can be developed by playing digital signals to generate sound, text and visual media? The eight works produced demonstrate the broad range of instrumentation, forms, contexts and possibilities for musical compositions, installations and performance works that can be achieved by this process of slowing down and performing micro-temporal data transmissions.

Throughout this thesis I have analysed how the works have created new encounters with computers and challenged some of the ways in which we habitually use them. I have reflected on this from my own perspective as an artist developing and performing with such systems, from observing and talking with others using the systems, to reflecting on documentation and audience feedback. The encounters created physically and technically challenging ways to interact with computers and I witnessed them met with boredom, confusion, excitement and engagement and focus. I hope that this conclusion also serves as an introduction to possible future performances of the works and new directions for future research.

Chapter three, *listening to code*, contextualised the works within debates surrounding listening to computer signals. Here I argued that whilst works that use transducers to render electromagnetic signals into the sonic realm are able to provide insights into the location and strength of signals, they are not able to reveal how digital signals contain semantic information. I argue that the musical works I have developed provide an alternative approach to understanding ways in which digital information is transmitted and the semantic information it contains. I suggested that visual accompaniment can add further dimensions to revealing semantic information encoded in the signals.

Chapter four, *Transmissions, mappings and encounters*, explored the complex dynamics at play when presenting multimodal installations and performances where sound is translated into visual information. Through the examination of two performances and installations, I discussed how installations provide temporal and spatial possibilities that allow audiences to encounter the work for longer periods of time. What is lacking in the excitement of live performance is compensated for with the ability to have time to reflect on the processes involved.

My research demonstrated that during performances the more complex the audio input, the greater confusion over the mapping processes. In *Parallel Voices*, for instance, as noted above, it was sometimes assumed the pitch of the voice had something to do with the colours produced, and in *Cryptoguitar*, people were often interested in how pitch could be used to add another dimension of control. I concluded that although systems should be clear and work well, idiosyncrasy and confusion over process should not always be considered negatively. Moreover, I conclude that performances should be distinct from technical demonstrations: rather, they should try and engage the audience in the process of translation by combining what Don Ihde calls embodied, hermeneutic and alterity relations in such a way that the process appears like magic. This can be decoded by the audience later.

Chapter five, *Rhythmic encounters*, made the case for my research into rhythmic interaction with computers and the emphasis on human rhythm and performance. I follow the trajectory of thought articulated by André Leroi-Gourhan and Bernard Stiegler that humans developed language and technology through rhythm and embodied inscription processes. Stiegler has repeatedly argued that this exteriorization of memory, which is increasingly in the form of digital information, is problematic as it is open to manipulation by corporate interests. In this sense, my research could be considered a humble attempt to reclaim embodied inscription processes and find ways of applying them to the field of computer interaction. In more practical terms, I described how I sought to incorporate the fragile and demanding nature of playing live polyrhythmic music into the works I produced. I suggested that this was achieved most successfully with the work *Parallel Voices* which featured fluctuating tempos driven by entrainment: in other words, the group led the rhythm. I argued that my method of studying artforms such as Batá and flamenco alongside developing the works created rich ways to approach how the binary rhythmic patterns could be interpreted and played. They offered new ways of considering group interaction and participation in computer music. Finally, I contend that to spend time learning to play code with the body creates a human dimension to playing information that has qualities beyond other forms of computer based sonification. This finding is echoed in research by Alexandra Supper who uses the term “data karaoke” to describe the use of body skills to present data.

Chapter six, *Playing code*, explored the creative potential of using embodied actions to play symbolic codes as a means of musical HCI. I began by emphasising the need for the technology to be reliable and responsive. I then discussed how working within the very narrow parameters of playing ASCII patterns creates rhythmics constraints that can encourage creativity in much the same way that clave and compás do in Afro-Cuban music and flamenco respectively. To play code means creating symbols that are legible, and I give consideration to the meaning of the texts I chose to write and play alongside a summary of how language is embedded into other forms of music. These cover a wide range of subjects from religion to insults. From the research that has been undertaken so far, I believe that there is great potential for making more use of these systems within the field of live coding and that this could be done with more robust interfaces, the development of new live coding languages and creating translators for other existing drum languages. These outcomes from the research point towards new forms of technodiversity, which I would suggest should taken slowly, with care and with respect for the rhythmic artforms explored. For example, batá drumming did not find its way into the work I presented, it did not feel appropriate to augment it or make any changes to this beautiful music however its rhythmic demands greatly influenced my approach to developing *Parallel Voices.*

Some of the strongest examples of audiences understanding how digital communication works came through people actively encountering the systems: using the system rather than watching it being used. I believe that as communication technologies become faster in speed and smaller in size the fundamental qualities of digital processes become increasingly obscured. Therefore, the educational potential of this research should not be ignored. The accessible interfaces used in *Parallel Voices* and *Clapping ASCII* proved to be popular amongst a wide range of age groups and could be developed for educational work within schools and museums. Some preliminary work on this application of the work can be found in my accompanying portfolio under the work for *Clapping ASCII.*

The research highlighted that whilst simple systems, such as those developed for *Clapping ASCII,* can be engaging for general audiences, there is also great potential for the development of more sophisticated rhythmic interfaces designed for musicians and particularly percussionists who seek out challenging rhythmic encounters. Prototypes of these were used in

Duplex Drumming and *Cryptoguitar* and offered standalone portability, USB power, text out, midi connections, in-built speakers. This made them reliable, easy to use and compatible with other software and hardware. The range of interpretations, mappings and outcomes possible from combining these interfaces with musical instruments are vast. They could be expanded on and developed further through open source code, the release of software, hardware and musical scores that can be accessed and played by a wide range of people.

Further media archaeological methods could certainly be employed to translate more of the vast array of digital communication systems, and these could be readily implemented into the software I have developed. For example, within quadruplex telegraph developed by Thomas Edison in which four separate signals can be transmitted on one line would be fascinating to develop into a multi modal performance piece. However, such increases in complexity would be likely to have a negative impact on an audience's ability to understand what is happening in the work and would be no doubt harder for musicians to perform. However, it not always necessary for the audience to grasp exactly what is going on and, as described in this thesis, there are plenty of instances in musical history where complexity has been favoured over simplification, including as Messiaen's use of multiple translation systems or the dense information found in polyrhythmic music from Cuba.

The process of *playing code* presented in this research has demanded the development of new interfaces, playing with rhythmical accuracy and repetitive practice from performers. I have argued that the works brought together embodied relations and hermeneutical relations with technology in unique ways that fulfil the conditions required to reach a state of flow. The works have revealed some of the ways in which semantic information can been concealed within signals and I hope it inspires others to explore the potential for inscribing text with music.

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