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Expressive Temporalities: A Guide to Augmented Drumming

by

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Abstract

This thesis offers new possibilities for using the drum set, an instrument long associated with keeping a steady track of time, to create temporalities that extend beyond linear time or regular rhythms. Through sensor technologies that analyze and augment a drummer's physical gestures, a new landscape of contemporary drumming and music has become visible. In tracing the origins of this new landscape, a historical and musical link between significant drummers and technologists - occupants of seemingly opposite ends of a spectrum of musical invention - is established by examining key technological innovations that have enabled drumming technique to flourish. The goals and influence of music production techniques related to recording, synthesizing, sampling, and analyzing the sound of the drums will be shown to have just as significant an impact on the techniques employed by drummers today as any work by drum set pedagogues.

The interwoven trajectories of recording, synthesizing, sampling, and analyzing the sound of drums have culminated in a tool called Sensory Percussion that has been used by the author to create two distinct bodies of work; one focused on pieces for solo drum set, and the other focused on interactive and collaborative work. As each piece dictates, this thesis goes on to present a series of methodological approaches for anyone seeking to augment their drumming practice by using this technology to facilitate new musical and collaborative forms. The methodologies range from larger aesthetic concepts such as exploiting the visual and sonic causality of striking a drum to very specific technical methods for training and mapping within the software. They are ultimately highly personal methodologies that are in no way prescriptive, but merely a series of routes, out of many, to creative applications of a technology that represents a potential paradigm shift in the role of the drum set in contemporary music.

By augmenting the capabilities of the drum set, a hidden layer between the input and output of a drummer's work makes itself more apparent. In this hidden layer, we find a web of interlocking temporalities that drummers must maintain. In the macro, this web includes the structure of a piece of music and its sequential unfolding, or, in the micro, the moment to moment fluctuations in event timing that make up a piece of music's tempo. In devising these works, the sense of temporality that is created by the direct causal relationship between striking a drum and its resultant sound has become a parameter to explore alongside rhythm. As each piece presented in this thesis was developed, it became clear that exploring ideas related to

musical time outside the realm of the drum set could lead to novel results. As such, a discussion of temporality and its relationship to a new musical interface called The SOFTglass, developed by the author and based on an hourglass is presented. This project became another way to sonify event data in an effort to upend our expectations about sound and its relationship to time.

The landscape of augmented drumming is growing as more drummers decide to add sensors to their instruments. The forerunning attempts to use drumming as an interface for electronic music production have achieved increasing prominence on stages and in studios everywhere. Some of these tools have taken decades to reach widespread use. It is a tantalizing prospect to consider the effects that the same widespread adoption of sensor technology, and Sensory Percussion in particular, could have on the wider landscape of contemporary music.

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Chapter 1

Introduction

The spectrum of musics that feature the drum set that has developed since the instrument's inception near the start of the 20th century has expanded to the point that a new set of tools for widespread adoption that augment or redefine the sound of the drums is warranted. The collection of membranophones (instruments that produce sound from a tightly stretched membrane that can be struck, plucked, rubbed or sung into) and idiophones (instruments that produce sound through the vibration of the item itself, such as a stick or cymbal)[1] that make up the drum set have gone through but a few meaningful design changes since they began to be assembled as a single instrument. Drum technology innovations that made modern technique possible were more often the implements for playing the instruments themselves, such as the bass drum pedal and the hi-hat stand, which evolved from the "low-sock" (as early iterations amounted to a hinged board with cymbals attached, worn under the left shoe) or "low-boy" cymbal[2] and were crucial in the transition from percussion sections to a four-way interdependent rhythmic technique played by an individual performer. The sizes of the cymbals used on the low-boy grew from around 8" to today's standard 14" hi-hat, which increased the available surface area for playing with sticks, itself a development made possible by extending the height of the original low-boy apparatus from ~9"-15" off the ground to ~4'[3]. Tuneable tom-toms evolved from "Chinese tom-toms", colorfully-adorned small wooden shells with calfskin heads

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[1] Deborah Lee, "Hornbostel-Sachs Classification of Musical Instruments" (Encyclopedia of Knowledge Organization, eds. Birger Hjørland and Claudio Gnoli, 2020), https://www.isko.org/cyclo/hornbostel.htm.
[2] Steve La Cerra, "The Modern Drum Set Part 5: Cymbals and Hardware," yamaha.com, *Part 5: Cymbals and Hardware*, April 21, 2020, https://hub.yamaha.com/cymbals-and-hardware/.
[3] Hugo Pinksterboer, *The Cymbal Book* (Milwaukee, WI: Hal Leonard, 1992).

tacked on, and eventually took on a wide variety of diameter, depths, densities, and materials[4]. What's important to keep track of here is that despite these changes in drum set technology, a person born in 2001 could largely play their same contemporary playing style on equipment from 1930, just as a painter today can express contemporary visions through a historic medium.

In considering the seemingly perfected design of each drum in the typical drum set - bass drum, snare drum, and tom toms - it is important to note how technologists have enabled these developments, the effect this has on communicating musical ideas, and how this is not particular to the drum set. For example, as we will see in this chapter, the introduction of standardized tuning pegs on mass-produced drums after WWII were essential for helping standardize the *sound* of drums and ensuring their musical proliferation through following generations. In James Blades' *Percussion Instruments and Their Histories,* we see this in drums from all over the world and through history, such as the development of ancient slit drums (a hollowed, carved log with a slit in the top, creating two tongues for striking) from means of communication across distances to melodic arrangement for communal ritual[5]. This progression had as much to do with the technologies available at that time - presumably stone tools that could whittle at the underside of the tongues of a slit drum to create two different tones - as any other factor. Furthermore, according to Blades' research, the slit drum seems to have been a design that was arrived at by many groups of pre-civilized humans, suggesting that technological developments, whether stone tools or machine learning, will quickly find themselves being applied towards musical ends.

With today's drum at a near-perfected design stage, the development of today's many contemporary drumming styles has arguably been driven more by recording technology than by drumming technology. With every change in the technology of music recording and dissemination, we find people embracing, and sometimes anticipating, these changes in their playing styles, creating an ongoing dialogue between human behavior and technology. As musical applications of the drum set have grown to include sound production techniques of synthesis, sampling, and timbral recognition, this chapter establishes the trajectory of these disciplines as initially separate and becoming more recently fused through a growing community of drummers using the Sensory Percussion system to augment their playing with sensor technology.

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[4] J. Bradford Robinson, *Drum Kit* (Oxford University Press, 2001), https://doi.org/10.1093/gmo/9781561592630.article.42868.
[5] James Blades, *Percussion Instruments and Their History* (New York: Frederick A. Praeger, 1970).

1.1 A Technological Evolution of Drumming Styles

Modern drumming technique began in the beginning of the 20th century when Black ragtime musicians in New Orleans[6] first sat down and played a bass drum and snare drum (each evolving from Turkish drums from the 1300s, the davul[7] and tabor[8], respectively) with assorted cymbals and non-pitched percussion all at the same time. Also known as a "trap kit" or "traps" (abbreviated from "contraption kit" due to the wide array of instruments at one's disposal[9]), the playing of these instruments had previously been delegated to separate musicians, a practice which evolved out of the parade origins of snare and bass drums themselves. As music shifted from churches and battlefields and began to include theaters and other indoor venues for new forms such as musicals, the confines of orchestra pits created a need for a single musician to cover the entire percussion section on one set of "traps". This practice had begun in the Reconstruction-era U.S. and was applied to the music popular at that time. It wasn't until the contraption kits, marching rhythms, and military bass and snare drums combined with the rhythmic propulsion of ragtime through syncopation that modern drumming, and the instrument used for it, began to take shape.

Figure 1.1: excerpt from Ludwig Company's 1928 catalog showing first known marketed and mass-produced hi-hat stand alongside low-boy stand

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[6] Jon Cohan, *Star Sets: Drum Kits of the Great Drummers.*(United Kingdom: Hal Leonard, 1995).
[7] Blades, *Percussion Instruments and Their History*.
[8] David A. Brensilver, "History of the Snare Drum: Eight Centuries of Innovation & Ingenuity," *Drum! Magazine*, September 10, 2015, https://drummagazine.com/history-of-the-snare-drum/.
[9] Robinson, *Drum Kit*.

1.1.1 "Baby" Dodds, Jo Jones, and the Path to Four Limbs

Warren "Baby" Dodds (1898-1959) was perhaps the most prolific and best known of this early playing style that paired a "four-on-the-floor" bass drum pattern (where each dominant pulse of the music is articulated by the bass drum, a technique prevalent in much of today's electronic dance music idioms) with press, or "buzz", rolls on the snare drum to drive the rhythm of the early jazz bands he played with. He was also the first person to make an unaccompanied solo trap set recording[10], which inadvertently kickstarted a project of liberating the drummer from its role as musical timekeeper that generations of drummers, including myself, have continued to contribute to. Despite his propensity for innovation, he claimed to not like playing cymbals, preferring to keep time with the press roll technique and his assortment of woodblocks. This preference makes sense given the acoustical nature of phonograph recording technology at the time of his work with King Oliver's Creole Big Band in 1923[11] — with the entire group recording into one non-electrified cone, woodblocks were especially useful for cutting through the rest of the instruments. Worth noting is his playing style on these surviving recordings, which seems to draw as much from the two-limbed rhythmic mode of expression known as tap dancing as it does from any known drumming tradition. Despite the many innovations that Dodds brought forth, hi-hat innovation was driven by the following generation of players. By the time the new hardware was marketed by Ludwig in 1928 (fig. 1.1), a new generation was primed to develop the cross-armed playing style that remains commonplace today. This coincided well with the advent of radio, microphones, and electrical recordings, as their increased fidelity allowed for people playing the drums to be heard with that much more clarity.

No surprise that the people that followed Dodds, including "Papa" Jo Jones (1911-1985) and Gene Krupa (1909-1973), pushed drumming to new heights of both bombast and sensitivity. Krupa, who became a national celebrity with Benny Goodman's "Sing, Sing, Sing" (1937) and helped jazz reach its peak popularity in the U.S., exemplified the brash, relentless, tom-tom driven sound of big band drumming. He was also the first celebrity endorser of a drum company, and together with the Slingerland company he standardized many elements of today's

[10] All About Jazz Staff, "Baby Dodds: Talking And Drum Solos," All About Jazz, November 3, 2003, https://www.allaboutjazz.com/talking-and-drum-solos-baby-dodds-atavistic-worldwide-review-by-aaj-staff.php#:~:text=It%20contains%20the%20first%20solo,in%201946%20over%20eight%20tracks.

[11] Rick Mattingly, "Warren 'Baby' Dodds," *Percussive Arts Society Hall of Fame*, 2011, https://www.pas.org/about/hall-of-fame/warren-baby-dodds.

drum kit, including cymbal-naming and tuning conventions[12] (fig 1.2).

Figure 1.2: cover and excerpt of Slingerland's 1936 catalog. The "Radio King" snare introduced several technological innovations like threaded tension-rod lug inserts to the snare drum design that remain standardized today.

Jones, by contrast, was one of the first jazz drummers to exploit higher recording fidelity by embracing the softer sound of wire brushes for timekeeping on the snare, a vastly more delicate approach compared to the previous generation. He was considered the first to master the new technique of playing the hi-hats with his sticks while opening and closing them with his left foot[13], and is generally considered to be responsible for perhaps the most characteristic element of "modern jazz" drumming, which is to keep time with the left foot/hi-hat, rather than the driving right foot/bass drum timekeeping of the swing era[14]. With Krupa and Jones' work combined, a new neural pathway for four-limbed rhythmic expression was firmly established.

1.1.2 Technology Pushes Technique - "Philly" Joe, Max Roach, Roy Haynes

As jazz turned to bebop, it became increasingly complex and divorced from a broad social context. So too did the drumming technique. Drummers of this era developed a rudimental technique that was previously never attempted, with ever-increasing precision, polyrhythmic

[12] Shawn C. Martin, "Gene Krupa Biography," n.d., http://www.drummerman.net/biography.html.
[13] Daniel Glass, "Drumming Innovators: Papa Jo Jones," September 5, 2012, https://web.archive.org/web/20151008213202/http://www.drummagazine.com/features/post/innovators-part-one-papa-jo-jones1/.
[14] Papa Jo Jones, Phil Schaap, and Paul Devlin, *Rifftide : The Life and Opinions of Papa Jo Jones*(Minneapolis, UNITED STATES: University of Minnesota Press, 2011), http://ebookcentral.proquest.com/lib/calarts/detail.action?docID=784154.

complexity, and tempi. The people who developed this style form the pantheon of the biggest names in jazz drumming of the 20th century. "Philly" Joe Jones (1923-1985), Max Roach (1924-2007), and Roy Haynes (1925-) are among the most well documented of this era and style, and they helped set the standard for jazz drumming excellence that remains essentially unchallenged to this day. It is worth noting their consecutive birth years in the early-mid 1920's, making them all young men in the post-WWII economic boom years. This period of broader economic prosperity combined with a racially segregated music industry to establish a drive among many post-war jazz musicians of this time to establish themselves as "challenging artists"[15], a drive which expressed itself in the drumming world through technical and compositional developments that explored the melodic and harmonic possibilities of an instrument made up of non-pitched elements. Also of note is the standardization of the hi-hat by Ludwig not long after these specific drummer's births, making it a native part of their drum set education. This generation of drummers would liberate their left feet, developing the hi-hat as a rhythmic equal to be incorporated into rudimental phrasing. Drum performances of this time were still likely to be recorded with a single microphone, but recording technology would vastly improve through the advent of magnetic tape in the 1940s to better capture these new highly refined instrumental techniques[16]. This cohort also benefited from the advancements in recording technology that enabled the modern record industry in that it allowed for a method of study that could take place between a record and a listener. Studying the recordings of a previous generation ensured that this generation of drummers would push the technical ceiling of their instrument defined by the previous generation. This helped accelerate the advancement of drum technique that has continued through today.

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[15] Clive James, *Cultural Amnesia: Necessary Memories from History and the Arts* (W.W. Norton & Company., 2007), https://archive.org/details/culturalamnesian00jame/page/163/mode/2up.
[16] Richard James Burgess, *The History of Music Production*(Cary, UNITED STATES: Oxford University Press, Incorporated, 2014), http://ebookcentral.proquest.com/lib/calarts/detail.action?docID=1696420.

Figure 1.3: Max Roach endorsing Gretsch Drums in 1959. The design of the drums have not significantly changed from fig. 1.2.

1.1.3 Rock Drumming and the Codification of the Drum Set

By 1965, The Beatles had appeared on The Ed Sullivan Show (fig. 1.4), people everywhere started a band in their garage, the hi-hat and its attendant technique had become the norm, and the drum set was more or less standardized. The increase in rock music's volume in sales and decibels drove the most meaningful design changes that drums and cymbals would undergo for a generation, as the instruments would need to project at louder and louder volumes while being suitable for standardization and mass production. The most significant changes would come in size and material, while the most substantial technological innovations in music were shifting from instrument technology to recording technology (perhaps the biggest recent innovation in cymbals has been to simply stack them to create a sound mimicking an electronic cymbal, handclap, or snare). Pop music experimentalists such as The Beach Boys and The Beatles had paved the way for many groundbreaking production techniques that remain immensely popular. Perhaps owing to their continued popularity, innovations in drum design have largely been frozen in time since then.

Figure 1.4: Greatest product placement for a drum company ever?

1.1.4 Multitrack Recording and "Linear" Drumming

A particularly powerful development in how drum performances were perceived was that of multitrack recording (fig. 1.5). A drum kit could now be recreated with unprecedented clarity on a recording, and as a result, drumming technique would continue to undergo a generation of changes. This higher fidelity would make possible what is known as a "linear" playing style, which involves interpolating a line of subdivisions across individual limbs and instruments so that no two voices sound together[17], rather than the prior generation's style based around cyclically alternating hands and drums, usually with a kick drum maintaining the pulse underneath. With such clarity, the pulse did not need to be continually reinforced in this way. The linear approach began with funk musicians such as James Brown's two drummers Clyde Stubblefield (1943-2017) and John "Jabo" Starks (1938-2018), and was truly developed by drummers like Dennis Chambers (b. 1959), Leon "Ndugu" Chancler (1952-2018), and Prince

[17] Gary Chaffee, *Linear Time Playing: Funk & Fusion Grooves for the Modern Styles* (Alfred Publishing Company, Incorporated, 1993), https://books.google.com/books?id=YSEMyghpihMC.

(1958-2016), who also embraced the coming wave of drum machines. With multitrack recording, rapid-fire 32nd note flourishes interpolated between drums and quieter elements like closed hi-hats and splash cymbals could be properly balanced to be heard on record as clearly as how the player heard it. This brought about a major evolution in drumming, as the quest for young drummers to attain the "modernity" of bebop drummers was supplanted by the "linearity" of funk and pop drummers And yet, this cohort did more than merely push drum technique forward. The still-formidable record industry of this era ensured these drummers' performances were made widely available. As a result, through a nascent form of repurposing vinyl recordings known as "sampling", their performances would inspire a new generation of music makers and provide the backbone of forthcoming sample-based genres like hip-hop and drum-n-bass.

Figure 1.5: Dennis Chambers with Parliament-Funkadelic. Note the array of microphones and their distance to the kit.

1.2 An Evolution of Drum Synthesis

The acoustical complexity and sheer volume of drum sets mean that reproducing their sound through microphones, whether for a performance or a recording, takes careful preparation and considerable resources when compared to other instruments in an ensemble that would typically feature a drum set. A significant (and perhaps disproportionate) amount of any engineer's time goes into getting a good drum set sound. This acoustical complexity when paired with the instrument's relative simplicity in operation (strike idiophone or membranophone with a stick, itself an idiophone) has positioned the drum set as a clear target for technologists looking to apply innovations in electronic sound synthesis and production to a familiar interface. In addition, the gestural connection of drumming to the sonic end result has prompted technologists to develop tools to perform rhythms that would be unplayable for a human. From Leon Theremin's 1931 *Rhythmicon* (fig. 1.6) that could play impossibly difficult polyrhythmic combinations[18] to the Roland's famous 1980 TR-808 drum machine, using a machine to create and play drum sounds has been motivating music technologists for decades.

Figure 1.6: The Rhythmicon and Roland TR-808, developed roughly 50 years apart.

1.2.1 A Cursory Look at Electronic Drums

While the Rhythmicon was being developed, the hi-hat had just begun to offer the prospect of four way rhythmic interdependence that would take decades to evolve. The idea of electronic polyrhythmic expression was not yet tied to the idiomatic instrumental technique of playing a standard four- or five- piece drum kit. Once that did develop, however, electronic modifications

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[18] Thomas Brett, "Virtual Drumming: A History of Electronic Percussion," in *The Cambridge Companion to Percussion*, ed. Russell Hartenberger, 1st ed. (Cambridge University Press, 2016), 82–94, https://doi.org/10.1017/CBO9781316145074.007.

to instruments that the drums accompanied in rock music, such as effect pedals for electric guitars, encouraged the electronic modification of the drums. The first attempt to create an electronic drum is attributed to Dutch drummer Felix Visser, who in 1971 modified an Ace Tone drum machine (Ace Tone was the first company started by Ikutaro Kakehashi, who would go on to found Roland) to allow the sounds to be playable in real time as a drum[19]. This homemade version provided a working proof of concept as the idea of a central drum computer, or "drum brain" as they came to be known, that was controlled by separate pads became the template for the majority of electronic drums to this day. The concept was solidified into a commercial product with the Pollard Syndrum, which failed to reach the level of commercial success that the Simmons company would eventually attain in the 1980s with their "SDS" line. Their iconic hexagonal drum pads accompanied top-selling pop acts of this era, such as Duran Duran, and established the electronic drum set as a viable instrument in an increasingly electrified musical landscape. Electronic drum kits today have only improved in their similarity to acoustic drum sets in visual design and playing material, evolving from hard rubber, to felt, to mesh heads that respond much like an acoustic drum when struck with a stick. These instruments are largely stuck within the existing paradigm of acoustic drum sets and their primary advantages are to those looking to practice without bothering neighbors, as electronic kits allow the sounds to be sent to a pair of headphones for the drummer to practice privately. Far from being an instrument for new modes of expressivity, they merely attempt to solve some of the problems posed by acoustic drums.

Figure 1.7: Simmons SDS-5 electronic kit with drum brain (behind upper left drum)

[19] Mike O'Connor, "The History Of Electronic Drum Sets - 1960s to the 2020s," ElectronicDrumAdvisor.com, September 10, 2020, https://www.electronicdrumadvisor.com/history-electronic-drum-sets/.

Despite the acoustical complexity of drums and cymbals, their melodic function in a given piece of music is generally a byproduct of the instrument, which gave technologists like Laurie Spiegel significant room to develop synthesized drum sounds that had their own tonal characteristics. Spiegel's piece "Drums" (1975) showcases the success of this approach. This piece demonstrated the warmth of short, round, tom-tom-esque sounds, the blueprint of which can be heard in the analog drum sounds from the aforementioned Roland TR-808 drum machine, an innovation also driven at least partially by a desire to tame the acoustical complexity of the drum set for home-studio music making. She also claimed to approach the computer as a folk instrument[20], which is something that has made itself plainly apparent in the work of today's hyperpop practitioners who have such dexterity with this folk instrument that, when combined with the availability of recorded media, approach pop music *history* as something of a folk instrument as well.

1.2.2 Musique Concréte and Research Laboratories

Many of the advancements in electronic sound and synthesis made by technologists of the 1940's-1970's took place at research facilities that were either funded by academia or by the corporate conglomerates of the time. Laurie Spiegel, for example, worked for Bell Labs, a subsidiary of Western Electric and AT&T, while the famous Mark II Synthesizer lived at the Columbia-Princeton Electronic Music Center and was a project of electronics giant RCA[21]. For a period, innovations in technology as applied to music were largely the realm of well known composers of the mid-20th century (names like Varese, Cage, Reich, Subotnick) or employees of research facilities (Spiegel, Wendy Carlos). These composers owed as much to pre-WWII European avant-garde composers like Arnold Schoeberg or Igor Stravinsky as they did to developments in the manipulation of magnetic tape, spearheaded by Egyptian ethnomusicologist and composer Halim El Dabh[22] with his piece "The Expression of Zaar" in 1944 and later dubbed "*musique concréte*" by French composer Pierre Schaeffer[23] in his 1952 publication " In Search of a Concrete Music". This process involved painstakingly cutting up reels of magnetic tape and pasting their sliced up bits back together in new arrangements for playback on colossal

[20] Kyle Gann, "Electronic Music," in *American Music In The 20th Century* (Schirmer Books, 1997).
[21] T. Holmes, *Electronic and Experimental Music: Technology, Music, and Culture* (Taylor & Francis, 2015).
[22] Fari Bradley, "Halim El Dabh: An Alternative Genealogy of Musique Concrète," November 30, 2015, https://www.ibraaz.org/essays/139/#_ftn1.
[23] Pierre 1910-1995. Schaeffer and James Tenney Collection., *A la recherche d'une musique concrète*, Collection "Pierres vives" (Paris: Éditions du Seuil, 1952), https://bac-lac.on.worldcat.org/oclc/299901046.

reel-to-reel tape machines. Early analog synthesizers were even more cumbersome and out of reach for those outside of these select circles. Due to this, sampling and synthesis techniques were things no drummer at the time would have had the ability to incorporate into their practice. It would take growing academic interest in the analysis of sound and timbre to allow drummers to eventually have a tool for using the drums as an interface for sampling and synthesis.

1.2.3 Timbral Recognition

Analyzing the true timbral complexity of membranophones and idiophones for use with electronic instruments and processing is a relatively recent endeavor. The development by Adam Tindale, Ajay Kapur, Ichiro Fujinaga, and George Tzanetakis of timbre[24] and gesture[25] recognition of percussive sounds provided a clear framework to further analyze not just data from one type of drum, but from a full kit. This work presented an early method of using neural networks and machine learning in a context of drumming, and while their stated goal was towards transcriptive and analytical ends, this innovation laid a foundation for a related but, at the time, unimaginable result. For a drummer to use their instrument as an interface for sampling and synthesis, they would need a physical controller that could withstand the impactful nature of drum set playing. Though the work of Tindale, Kapur, et al., was done with a microphone, the work of Roberto Aimi[26] attempted to approach the drum-set-as-interface from the physical perspective. This work used real-time convolution to augment and modify the sounds of existing drums through the creation of a series of percussion instruments augmented with sensors. The work of these academics, when taken together, formed the backbone of drumming's latest technological innovation.

1.3 An Evolution of Sampling

Although the development of the sampler would go through many iterations and generations before any more than a small minority of drummers could feel confident enough to appropriate them into their work, these changes contributed to a growing musical culture of at-home

[24] Adam Tindale, Ajay Kapur, and Ichiro Fujinaga, "Towards Timbre Recognition of Percussive Sounds," n.d., 5.
[25] Adam Tindale et al., "Retrieval of Percussion Gestures Using Timbre Classification Techniques," n.d., 5.
[26] Roberto Aimi, "Percussion Instruments Using Realtime Convolution: Physical Controllers," in *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, NIME '07 (New York, NY, USA: Association for Computing Machinery, 2007), 154–59, https://doi.org/10.1145/1279740.1279768.

hobbyists that would lead the next impact on drumming technique. The final two decades of the 20th century saw an explosion in music technology devices that would have a massive effect on how drumming technique would develop, though much of this technology borrowed concepts that owed to the basics of music theory and drumming (such as the 16-step convention in sequencers). Many of the advancements were driven by improvements to information storage and retrieval, and this led to a range of moderately priced samplers, sequencers, drum machines, and music workstations. These devices were previously only accessible to those in academia, scientific research, or the professional record industry. Their increasing availability led to a revolution in music that helped lay the foundation for hip hop, which would become the most popular style of cultural and rhythmic expression in the United States since jazz. Like jazz, technological innovation is intricately interwoven with hip hop's origin story. But by this time, an ensemble of musicians could be at the control of a fingertip, and yet again a new pathway for rhythmic expression would be explored.

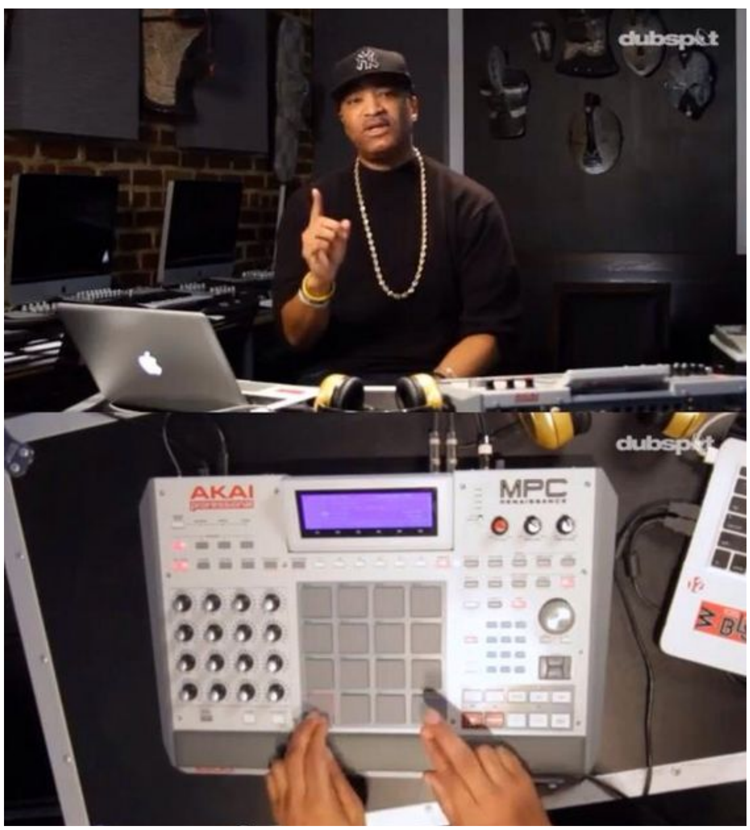

Figure 1.8: Marley Marl drumming on an Akai MPC (stills from YouTube)

1.3.1 "Break" beats and "The Bridge"

In 1984, Marlon Williams (b. 1962), aka Marley Marl, helped define a new sound of drumming for a generation with his fingertips, through the use of an Akai MPC workstation and a Roland TR-808 drum machine connected to a Korg sampler, a technique he used to create an ode to his NYCHA upbringing at Queensbridge Projects on the iconic early hip-hop track "The Bridge" with M.C. Shan. In a 2013 video where Williams discusses the creation and history of "The Bridge"[27], we can see him literally drumming with his fingers on the pad of his sequencer, playing the kick, snare, and hi-hat with the same resultant sound that a drum set player would achieve, but with a technique completely shaped by his interface. Another inventive appropriation of this technology that Marl brought forth was to use the drum machine to trigger a sampler loaded with kick and snare sounds from a record (the accompaniment-free section of The Honeydrippers' "Impeach The President" known as the "drum break", or simply, "break") that were then blended with the original sounds from the drum machine. This blending of triggered samples has incidentally formed the inspiration for a frequent technique in my methodology for use with sampler software, though like using the hi-hat "on 2 and 4", the technique has become so commonplace that it almost seems self-evident.

1.3.1.1 A Human Feel

In using the previous generation's soul, funk, and jazz recordings as source material for sampling (a markedly and practically different approach from Schaffer, Varese, and other concrete practitioners who frequently had to make their own recordings of musical instruments, cityscapes, natural elements, and other sonic phenomena), hip hop producers helped develop new ways that listeners and future drummers would hear and perceive rhythm. Cutting up breaks that captured the slight imperfections in human drummers' performances and reframing and resequencing them with the indifferent precision of a sampler or drum machine created all sorts of happy accidents that resulted in new ways that music would feel to listeners. The concept of rhythmic time-feel, central to drumming, was now in the realm of the hip hop producer.

[27] *Marley Marl "Classic Recipes" - Recreating MC Shan "The Bridge" w/ Akai MPC Renaissance* (Dubspot, 2013), https://www.youtube.com/watch?v=6IxUXfhC8TI&t=107s.

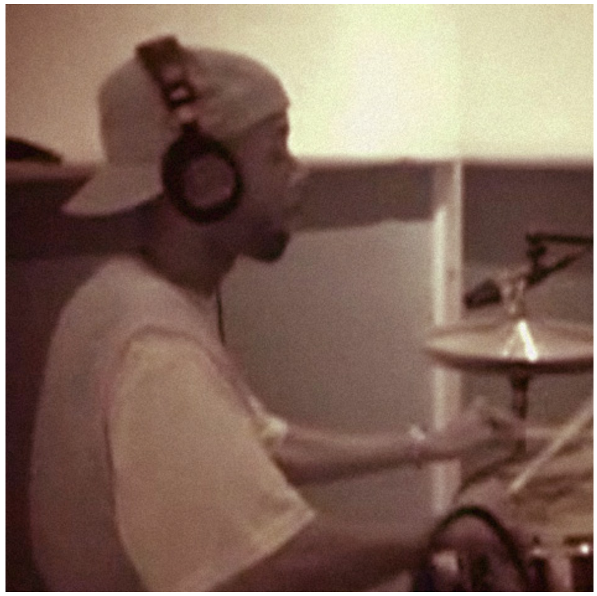

Figure 1.9: James Dewitt Yancey, aka "J Dilla", a producer who had a profound influence on a generation of drummers through his embrace of rhythmic imperfections.

1.3.2 J Dilla: Drumming with Samples

Marley Marl's influence was at once widespread and niche, much like "Baby" Dodds and his generation of foundational drummers. The influence of Marley Marl is perhaps more felt in the generation that followed, with producers like DJ Premier (b. 1966), Pete Rock (b. 1970), and RZA (b. 1969) each taking up his mantle and ensuring that hip hop would spread far beyond the Queensbridge Projects. Like the drummers that followed Dodds' cohort, this generation of producers would refine the techniques presented by the originators, help popularize the sound, and introduce some of hip hop's first real celebrity producers (without the need to tie their work and image to two turntables like their DJ precedents, producers accumulated mystique), including the aforementioned RZA, Dr. Dre (b. 1965), and Rick Rubin (b. 1963). Rhythmic time-feel would find a new standard-bearer in James "J Dilla" Yancey (1974-2006), who came of age in the wake of the aforementioned hip hop innovators. Dilla's work represented a pivotal cleave in this history as personal computers enabled music technology companies to shift their focus away from expensive hardware and more towards software development over the course of his life. He mastered the Akai MPC music workstation as an instrument, and his sample-based productions, which often featured drums that were intentionally at slightly different relationships to each other in order to create a sputtering or "slumped" time-feel, made him among the most influential music makers of the early 21st century.

Much has been written on J Dilla's influence and output as a producer. What is most important here is that his work as a producer became a significant reference point for an approach to rhythmic feel among drummers. By this time, drummers could learn from a combination of emulating drummers, producers slicing perfectly metronomic breaks, or this newer breed of producers represented by Dilla that were warping the breaks and their relationship to the beat in a way that embraced a human-like imperfection. But the practice of slicing and warping breaks to create rhythmic complexities was not solely the realm of hip hop.

1.3.3 Jungle & Drum n Bass: Learning To Drum Like The Computer

Once hip hop established the use and manipulation of drum breaks, particular breaks including the aforementioned "Impeach the President" break had proven their exceptional musical utility and were used repeatedly by producers looking to skip some of the record crate-digging work that producers before them had done. These breaks found their way onto a series of compilations released by Lenny "BreakBeat Lenny" Roberts and Louis "BreakBeat Lou" Flores between 1986 and 1991 under the Street Beat Records label. These releases, known as Ultimate Breaks and Beats, were intended for hip hop producers and included breaks best suited to their needs[28]. The auspicious first edition included the 1969 tune "Amen Brother" by The Winstons. The drum break from this tune, performed by Gregory Coleman, would eventually become the most sampled drum break in history, being sampled over 5500 times (by latest count at WhoSampled.com[29]). Many of these instances are attributable to practitioners of the Jungle and Drum n Bass sub genres. These at-home technologists and music makers took the break, typically used to accompany an MC in a hip hop track, and made it the featured element by raising the tempo and painstakingly splicing the rhythms (much like practitioners of "*musique concréte*" in the 1940s-1950s), rearranging them into labyrinthine polyrhythmic layers that provided an almost melodic function. The sheer tempi of Jungle and Drum n Bass tracks were enough to inspire a legion of drummers to attempt to recreate what they heard, and the impossibly chopped up grooves provided a worthy challenge for a certain breed of drummer.

These drummers, such as Jojo Mayer, Mark Giuliana, and D'antoni Parks, claim as much influence from drum-n-bass producers like Squarepusher or Aphex Twin as they might any of the aforementioned jazz or funk drummers. These drummers borrowed their techniques from

[28] Robbie Ettelson, "Ultimate Breaks & Beats: An Oral History," *Cuepoint* (blog), March 13, 2015, https://medium.com/cuepoint/ultimate-breaks-beats-an-oral-history-74937f932026.

[29] WhoSampled Staff, "Samples of 'Amen, Brother,'" Database, WhoSampled.com, accessed May 9, 2021, https://www.whosampled.com/The-Winstons/Amen,-Brother/sampled/.

studying music made with computers and then turned around and taught these techniques to other drummers in the time-honored tradition of in-person drum lessons. Through a reverse-engineering of music made with machines, the beginnings of post-modern drumming took shape as the trajectories of technology, drumming technique, and their origins started to turn in on themselves. Many drummers today are playing "drum and bass" or "Dilla" grooves without being all too sure of where these techniques originated. Still others are blending techniques from across history, practicing hi-hat techniques owing equally to Papa Jo Jones and Prince, each one a response to different technologies. As technologists and composers innovate in tandem, their successful innovations get absorbed and reabsorbed into the music making culture to the point of obscuring the source for all but the most historically minded.

1.4 Putting It All Together: Sensory Percussion

Technology and technique to drummers might seem completely at odds. Technology gets in the way of drumming, and technique gets you *out* of your own way of your drumming (if you accept the body as a limitation between one's ideas and their resultant sound on the instrument, making instrumental technique the eventual elimination of one's body as a barrier between idea and sound). But as we can see, there has been significant give and take between the two. Each new development in music technology is in response to, and then begets, a new technique in drumming. Each new technique in drumming is in response to, and then begets, a new development in music technology.

This cyclical relationship has led to the development of the Sensory Percussion system. Sensory Percussion represents a significant step forward in the merging of human beings and technology through rhythmic and gestural expression. It was developed in 2013-2014 by Tlacael Esparza, an excellent drummer and close friend of mine. Due to this privileged position as a beta tester and early adopter of the system, Sensory Percussion has been a central part of my artistic practice since its introduction in 2015. The system relies on a combination of sensors for each drum and the software that handles the timbral recognition. In this same software, the input can be mapped to a variety of output controls and effects. The system draws upon old and new technology in a way that previous attempts to electrify the drums could not. Inside the sensor are magnetic coil pickups and a mic preamp, magnifying the sound of each impulse. This technology is what drove the innovation and adoption of the electric guitar, one of the most prevalent tools for music-making spanning at least two or three generations in the 20th century.

However, it builds upon the work done in timbral recognition, analyzing the magnified drum signal for different sound "regions" based on training data provided by the player. The regions correspond to the different combinations of timbre achieved by hitting the drum in different places in tandem with the implement chosen (stick, brush, mallet, etc - although sticks work best). This process essentially creates a compositional space where drumming gestures are separated from their anticipated sound. The freeing of a sound from its source was of chief concern to some of the earliest adopters of electronic music and composition, such as John Cage, who's creative work began during a time when music was still nearly exclusively acoustic. The evolution of synthesis and sampling made this freedom possible in many ways for many musicians. Within the context of striking a membranophone or idiophone whose sound is determined by its physical properties (e.g., the weight and diameter of a cymbal, the depth of a snare drum and the air pressure inside), this system introduces this same freedom for drummer-composers.

In a half-dozen years of using this system in a wide variety of musical settings, certain methodologies, strategies, and aesthetic theories have arisen that guide my compositional practice. In the pages that follow, these methodologies and theories will be presented first in a chapter on how they relate to a series of pieces for a solo performer (myself in each case). Another chapter presents collaborative methodologies through the discussion of interdisciplinary and multimedia works, as well as a proposed model for trio interactions. A chapter on a NIME with related themes is presented. A concluding chapter offers discussion of future works.

Chapter 2

Solo Methodologies

The following chapter presents a series of methodologies for developing solo work for a percussionist using Sensory Percussion as part of an extended drum set configuration.

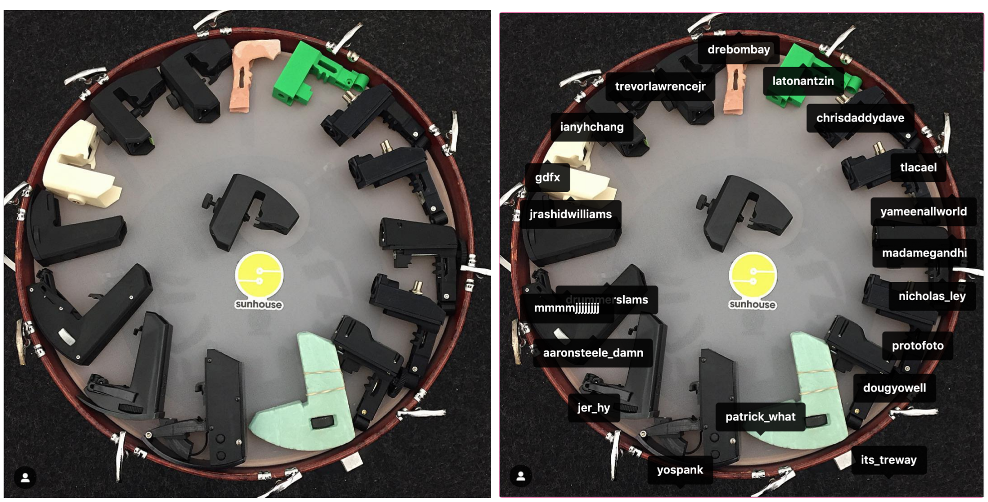

Figure 2.1: evolution of Sensory Percussion sensors, with social media handles to indicate early adopting group

2.1 Individual Strategies for Composition in Sensory Percussion

The composition process for Sensory Percussion takes place largely in the building and designing of the "kit", or preset array of samplers, controllers, effects, and MIDI output. The system differentiates between the possibilities of where on the drum a player strikes, and with what part of their stick. Each drum is assigned a user model for the particular combination of instrument, implement, and training data. In order to begin, the model must be properly trained.

2.1.1 Training The Sensor

The training process relies on a k-nearest-neighbor algorithm[30] that is commonly used in machine learning processes. In the work of Tindale, Kapur, Tzanetakis, and Fujinaga on timbral recognition of a drum, KNN machine learning is crucial to the development of their algorithm that is able to group training data from a drum according to different positions and implements. In Sensory Percussion, that same approach allows a user to create a set of playing data that corresponds to their specific "center", "edge", and so forth, depending on their drum, head, implement, and playing style. The system also responds to the gain-staging of the sensors, and can respond differently to different playing environments. For example, different venues can have different monitor or subwoofer placements on the stage which can affect how the sensor responds if it is not trained to ignore this input. Thus, training the sensors functions much like *tuning* them, as they can "detune" with consistent use.

Sensory's software offers 10 regions for mapping, plus a "void" region. Three regions apply to the drumhead: "center", "edge", and "damped", when a drummer uses their hand or other implement to press down on the drumhead, which increases the tension of the membrane and raises the pitch (a technique found all over the world of percussion playing). Four regions apply to a combination of the drumhead with another part of the drum: "cross-stick", achieved by resting the snare hand on the head and playing across the rim with the stick; "stickshot", leaving one stick on the head and hitting that stick with the other; "rimshot center", catching part of the rim with a center hit, and its respective "rimshot edge". The last three regions pertain to the rim and shell of the drum: "rim/tip", hitting the rim of the drum with the tip of the stick; "rim/shoulder", hitting the rim with the tapered portion of the stick near the tip, also called the stick's shoulder; and "shell", striking the shell or side of the drum itself. The crucial "void" region is for training the system for when to *ignore* input, such as from a nearby drum with similar tuning, or a heavy cymbal (like a ride cymbal) with a defined attack that has enough frequency resemblance to a stick-related region, often "rim/tip".

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[30]https://ecommons.cornell.edu/bitstream/handle/1813/31637/BU-1065-MA.pdf;jsessionid=9CF6F83705090CD5CD6BAA54D1F87B8F?sequence=1

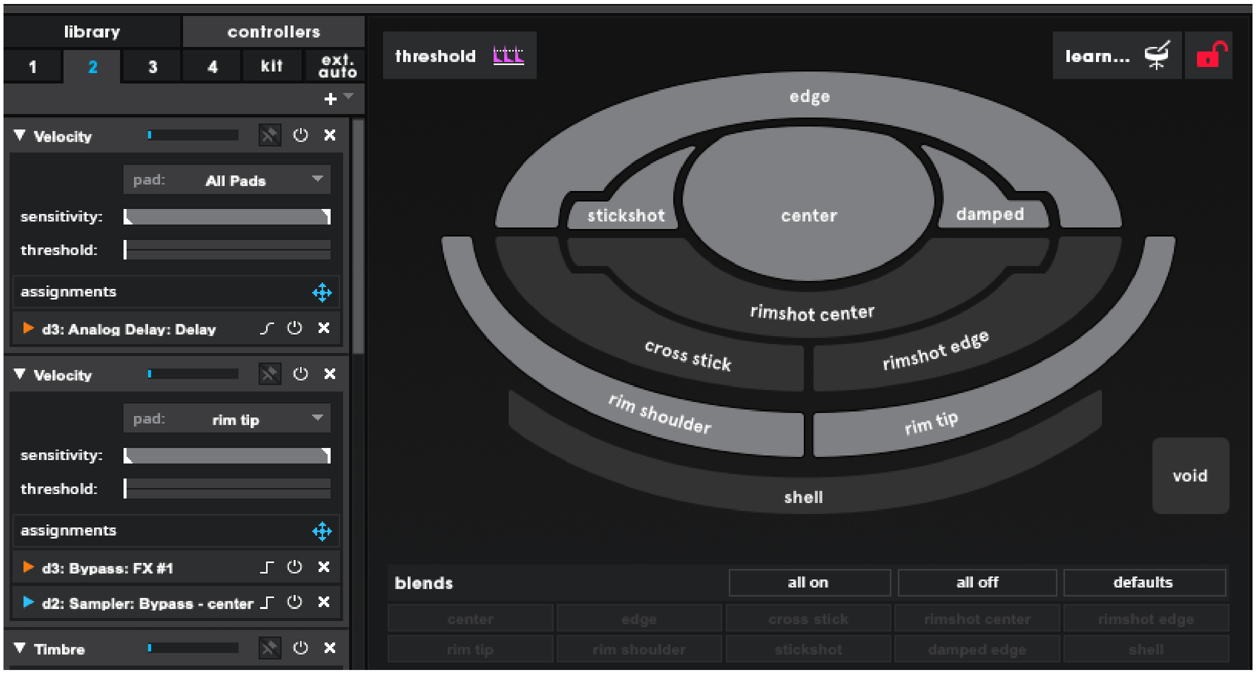

Figure 2.2: interface of Sensory Percussion software, with velocity controllers mapped between drum 2 (snare drum) and drum 3 (floor tom)

2.1.2 Mapping Strategy: Materiality

Though the system offers ten "regions" per drum, the most reliable results come from merging an understanding of traditional percussion instruments with the possibilities afforded by the software. If you consider a snare drum from a materiality perspective, three materials are in play: the plastic drum head, the metal hoop, and the wood of the stick and the shell (maybe your shell is actually metal - still the same three materials of plastic, wood, and metal). Three essential materials make up the possible acoustic surfaces, and within them are degrees of subtlety and difference.

Over time, I have come to realize that Sensory Percussion operates best under similar conditions. The "edge" region is essentially just a different part of the plastic drum head, and to map a sample or effect to the "edge" that is too different from the "center" can lead to unpredictable and unwieldy results, as the system is responding to subtle timbral differences with an algorithm that does not have a 100% success rate (though it's very close). Inevitably, misfires will occur. Instead I've found that the experience of drumming can be more faithfully recreated by mapping samples or effects to the "edge" region that directly relate to the "center" and that result in subtle changes to one essential sound. The blacked-out regions in fig. 2.2 show how I tend not to use 40% of the drum's possible regions (not counting the 11th "void" region), as the subtleties between the two rimshot types and the two hardware/stick combinations are too minute to have the software parse with consistency.

When striking a typical snare drum, much subtlety and difference can be achieved, but if one is simply using sticks, there's only so much room to explore the essential sound of a snare drum. This same principle is the core of the sample and effect mapping strategies for Sensory Percussion.

2.1.3 Controllers and Interface Arrays

The true expressive power of this system lies in the gesture controllers and in the strategies applied to their mappings (fig. 2.2). Drummers can map their velocity, speed, and timbre (or, thought of another way, location of a drum hit) to nearly any sample or effect parameter in the software. An additional Envelope controller uses a waveform editor triggered by velocity events to send different rates of attack/decay/sustain/release (ADSR) parameters as controls. In addition to audio processing, controllers can be assigned to MIDI control change (CC) messages on up to 16 extra MIDI channels, which enables a greater degree of collaborative possibilities through the broad range of applications of the MIDI protocol. Certain control mappings have become reliable in their effectiveness, and this chapter presents control mappings in audio, while the following chapter presents control mappings in MIDI.

Each sensor in this system has immense power. One of the most important decisions in the pre-composition stage is simply how many sensors to use, if one has access to more than one sensor. I've arrived at two primary approaches to sensor quantity: one that is geared towards electronic music, for use with "silent" mesh drumheads, with little to no intended acoustic input from the drums themselves; and the other a hybrid of acoustic and mesh drum heads, cymbals, and sensors. The two pieces that constitute this section, "Motus" and "Keep Time Keep Sake", outline the possibilities of these configurations.

2.2 "Motus" - Samples Can Sound Meaningful or Meaningless

"Motus" is a performance piece and video for drum set outfitted with Sensory Percussion. This piece employs a "hybrid" instrumentation, where acoustic drums, mesh drums, and cymbals are combined. Specifically, the instrumentation is an acoustic bass drum and snare drum with no sensors of any kind, processed through microphones and effects pedals, with two sensors on an acoustic floor tom and mesh snare, as well as the vitally important hi-hat, and ride cymbals. This instrumentation allows for possibilities of self accompaniment, where acoustic drums can be played against electronic elements that originate from, to a listener, an indeterminate source. In this case, the piece is split into an A section defined partly by sparseness in the acoustic drumming, and a B section defined by density in the acoustic drumming. Contrasts in density can certainly be applied to wholly electronic drum set works, but this takes on greater dimensionality and presence when merged with acoustic drums and cymbals that are pushing air molecules themselves.

2.2.1 Mapping Strategy: Intentional Pitch Ranging

The first mapping strategy this piece relies on is that of tying the velocity of the stroke to the pitch of the sample, in this case a sample of a bongo. Tying velocity to pitch is an effective way to control melodic elements, but when the range provided is every half step between +48 and -48 of the sample's base pitch, this becomes yet another potentially unwieldy and unmusical gesture. Due to this, setting the pitch range to something more manageable is an important step in mapping velocity to pitch. Following the selection of a manageable range, selection of possible pitches in the new range through quantization creates tonal centers and clearer motivic development. In the case of this piece, I set the range of the bongo sample to -48 to 0, where the softest hits trigger the lowest notes in the range, and through pitch quantization I set the possible pitches within the range to be only the root, minor third, and minor seventh. Thus, I've taken a range of 96 possibilities and pared them down to 12 (four scales between -48 and 0, three notes per scale). The result serves a sort of "bass line" function in this piece.

2.2.2 Meaningful Sampling

The piece was written during the Winter Session of 2021, and coincided with the U.S. House of Representatives' second impeachment hearing following the storming of the U.S. Capitol building on January 6, 2021. As a result, the politics of the moment are embedded in this piece through the inclusion of House Majority Leader Steny Hoyer's speech from January 13. This comes from an aesthetic theory that has arisen in my practice, which is that samples of human voices can sound meaningless or meaningful and that it just depends on the context.

This particular speech, while powerful and worth watching, is not included for its objective rhetorical significance. The reason for its inclusion is far more personal and comes from a practice of "distracted concentration", which comes from my undergraduate experience at the New School for Jazz. Pianist Hal Galper described practicing an aspect of one's instrument, like scales or rudiments to a metronome, while watching a baseball game (his example), or listening to the news in my case. I happened to hear this speech live through practicing distracted concentration by doing a snare drum rudiment ritual while listening to National Public Radio.

The sourcing of this sample is intended, on some level, to generate political engagement and awareness. However, it is not merely to stoke political ire, but to encode the piece with a layer of personal meaning. The inclusion of this speech imbues my performance of the work with the reminder of the distracted concentration practice through which I first heard it. It in fact enables further distracted concentration, as the sample, with its significant length (over 8 minutes), serves as an audio score and requires a portion of attention to always be paid to the speech. In this case then, the inclusion of this sample is also quite structurally significant. Once the sample is triggered, the piece cannot be any shorter than the 8+ minutes of the sample, even if no further drums are played. Each composition does allow for/demand a different approach to the meaning behind the inclusion of a given vocal sample (after determining whether or not vocal samples are appropriate for the piece at all). In each composition though, through application of this theory of personally meaningful sample sources, an externalization of one's inner emotional world is holistically evident and can help to break down a sense of detachment present in much of today's electronic music. A deeper sense of connection is fostered between the drummer, the software, and hopefully, the listener.

2.3 “Keep Time Keep Sake” - In Duo with Your Machine

Figure 2.3: “Keep Time Keep Sake”, then titled “These Drums Play Themselves” in performance at the Roy O. Disney Concert Hall, California Institute of the Arts, November 18, 2019. Note the apparent resting position - this piece requires minimal actual drumming.

“Keep Time Keep Sake” is a piece for playing Sensory Percussion in solo, and employs the wholly electronic configuration of four mesh drum heads and four sensors. This piece began by making use of the theory of meaningful sampling as I was exploring audio of Korean immigrants’ stories of coming to the United States. As the son of a Korean immigrant, these stories resonate deeply with me. While I lack the language of my mother, like many other second generation immigrants, the sound of the language triggers a nostalgic emotional part of my brain that connects me to my heritage. This emotional bond with sound fascinates me, and a desire to express this bond through a piece of music provided the spark of initial inspiration.

Conceptually speaking, the piece creates a tapestry of immigrant narratives that are linked musically through rhythm. As the narratives pile up and dominate the listener’s sonic landscape, individual voices and driving rhythms are eventually obscured and subsumed by the mass of the entirety. The multitude of voices is ultimately passed through the generative chain of LFOs detailed in the next section, and filtered not only in sound but in gesture, as it was my responsibility as the performer of this piece to simply start and stop voice/rhythm pairs at certain intervals of time by hitting velocity controllers on the rims of drums. Speed controllers assigned to the "center" on the snare allow for slight control of a global filter on the main mixer in Sensory Percussion, so the only other gesture at my disposal is a rapid drum roll that takes great effort and changes very little. The weight of the narratives accumulate on my gestures as they become increasingly abstracted and reabsorbed into a whole. The structure and sound of the piece directly draws from not just "immigration narratives", but also echoes my own personal experience as a second generation Asian-American filtering between the specific and exact "otherness" of my ancestors and the willing assimilation into human monoculture through cultural erasure.

2.3.1 Mapping Strategy: Generative Drumming Through The LFO

This piece makes use of a mapping strategy that pushes the system's capabilities of self-accompaniment by using its internal Low Frequency Oscillator (LFO) controller to continuously "hit" a drum within the software. Once the LFO is mapped to the region of the drum it's set to trigger, velocity controllers are then mapped to global audio track levels, simply using the act of hitting the drum to turn one of the continuous LFO drums "on" or "off".

The reason for using the internal LFO wasn't clear to me until I began to seek ways to use Sensory Percussion for generative music applications that would take me out of a position of control over every sound. Continuous solo work created a longing for collaborative playing, which I began to attempt through the use of very long samples. But this strategy led to predictable results. The use of the internal LFO provided the breakthrough to more generative possibilities that I sought. By mapping an envelope controller from a different region or drum to turn the volume up and down, this allows for a person playing this system to briefly sound a sampler loaded with a variety of drum samples being struck internally at a rapid rate. This causes a cascade of independently (and depending on the LFO frequency, randomly) timed events that provide an element to play "against" that can introduce a more improvisatory feel. Further exploration of that strategy led me to seek as discrete an independence between sound source and drum gesture as possible, which provides some of the technical genesis of this piece.

		LFO Mapping for "Keep Time Keep Sake"		
LFO number	**Assignment**	**Control**	**Frequency**	**Shape**
1	drum 3 - center	Trigger entire region	4 Hz	Sine
2	drum 3 - edge	Trigger entire region	5.99 Hz	Sine
3	drum 3 - rim tip	Trigger entire region	7.98 Hz	Sine
4	drum 3 - rim shoulder	Trigger entire region	15.98 Hz	Sine
5	drum 3 - rim tip	2nd Sampler (voice sample) - start time	13.81 Hz	Sine
6	drum 3 - center	2nd Sampler - start time	40 Hz	Random
7	drum 3 - center	2nd Sampler - pitch (range -7 st, -4.5 st), pan (50L, 50R)	.1 Hz	Sine

Table 2.1: Sensory Percussion interface and array of internal LFOs used in "Keep Time Keep Sake"

In "Keep Time Keep Sake", each LFO is set to a metrically related frequency set just slightly off from its true multiple (fig. 2.4.) and triggers a metallic percussive sound coupled with a different vocal sample for each region. As the layers of interrelated rhythms build, the layers of interconnected narrative build on top of the rhythmic bed. In the midst of this, I act as a way point for these streams, attempting to control which ones sound when, and which relationships are given time to build. This control is accessed via controllers on the bass drum (drum 1) hoop that are assigned to the samplers on the floor tom (drum 3). This same mapping is repeated with additional unused regions of the kit, such as the rim of the snare (drum 2). Each stroke on a different drum powers a different narrative set to its own rhythms. This highly personal composition is nonetheless built on very specific methodologies for the use of this system with regards to sample source and self-accompaniment that can be of use to other compositions and other performers.

Chapter 3

Interactive Methodologies

The following chapter proposes a series of methodologies for approaching interactive multimedia settings while using Sensory Percussion as part of an extended electroacoustic drum set configuration.

Figure 3.1: First-time interaction with TouchDesigner artist Kai-Luen Liang, February 2020. Graphics were mapped to drum gestures to manipulate visuals.

3.1 Sensory Percussion as Data Waypoint

Sensory Percussion enables new heights of expressive audio control due to the sheer amount of data it collects from a drummer's performance. Thanks to the aforementioned work in the fields of timbral recognition and real-time convolution, acoustic information from the sensors is parsed based on machine learning algorithms into the necessary regions that the software recognizes. This advancement required a software interface, so early versions of Sensory Percussion's sensor relied more on sending and controlling MIDI information, a tried-and-true music information protocol that would enable the use of the actual sensor with preexisting DAWs while the developers hacked away at what became a quite elegant software. The flexible nature of MIDI means that a drummer using Sensory Percussion can also interact with a wide range of instruments and software. In particular, TouchDesigner enables the control and manipulation of real-time interactive visual media, which has had creatively expansive effects on the work in this thesis.

3.1.1 MIDI Mapping in Sensory Percussion

There are numerous ways to use MIDI data with Sensory Percussion. With 16 MIDI channels and 127 MIDI CC numbers, it can be useful to one's workflow to employ a strategy for setting up the MIDI control parameters of the system. Establishing a template file is the simplest way to do this within the software. The MIDI template described below has been applied to a single drum but can be repeated on additional drum/sensor pairs and can be applied to any software that receives MIDI. My work in hybrid electroacoustic and interactive visual settings allows for a distribution of functionality among sensors so that no single element of these works, whether acoustic or electronic, sonic or visual, dominates the result.

To borrow from the Materiality strategy in the previous chapter, each material of the drum receives each controller type. In this case, that means establishing velocity, speed, and envelope controllers on the center and rim tip. Each of these are then mapped to their own MIDI CC knob in the interface. Timbre controllers are mapped to detect movement from center-to-edge and rim-tip-to-rim-shoulder and are also mapped to their own MIDI CC numbers. Finally, note messages are mapped to the center and rim tip. If working with multiple drums, it is crucial to note the MIDI channel that each drum is sending information to. And aside from working with a synthesiser to play MIDI notes, it's usually sufficient to choose C1 (MIDI number 24) and C#1 (MIDI number 25). While this mapping can be extended to include whatever range of MIDI notes are suitable for whatever piece of music is being developed, limited melodic variation from the striking of a drum tends to lead to more musical results. This is an extension of the Materiality strategy, wherein a drum's melodic capabilities are rich yet still restricted to the range allowed by the shell's size or the drumhead's density. Unless it's integral to the piece, a drum that triggers a wide range of notes is difficult to control with the same precision one selects pitches on any natively pitched instrument, so it's unclear what the musical advantage of such a configuration would be. If it is generativity one seeks, there are more effective ways to attain this, such as the internal LFO strategy used in "Keep Time, Keep Sake", discussed in the previous chapter.

The availability of MIDI data opens up significant avenues for a drummer or percussionist seeking to work in interactive multimedia settings. In a solo setting, a drummer or percussionist can be in control of a completely synesthetic experience where all sound and visuals are linked to the drummer's gestures as Sensory works in collaboration with TouchDesigner over MIDI. In a collaboration with other artists, a drummer can express rhythm and time in ways that influence the decisions of visual makers as well as sound makers, and for the decision making of the drummer to be as influenced by visual stimuli as it is by sonic stimuli. Through works presented in this chapter, both approaches are covered in detail.

3.1.2 TouchDesigner Mapping Strategy

The control of visuals through the drum set in particular is a mode of expression that is a new field for myself and for the community of drummers in general. For this reason, a mapping strategy for use with TouchDesigner is helpful in establishing an interactive workflow. This section is intended to supplement the knowledge of a drummer or percussionist already learning visual programming in TouchDesigner. For those unfamiliar with TouchDesigner, their website offers documentation and a free download of the software (derivitave.ca). An overview of how to use TouchDesigner after Sensory MIDI information has been successfully mapped in all but the most conceptual ways is beyond the scope of this document.

MIDI mapping in TouchDesigner is slightly unintuitive and relies more on MIDI numbers rather than note information. Memorization of MIDI numbers can aid this process, at least for orienting around C1/MIDI#24. TouchDesigner's MIDI mapping dialogue, when accessed, provides a stream of the raw MIDI data it is detecting as organized by MIDI number. When testing a new mapping, it is necessary to know the MIDI number of the "note on" message associated with whatever region you are using to test (the center region being the most likely choice) so that it can be properly assigned within TouchDesigner.

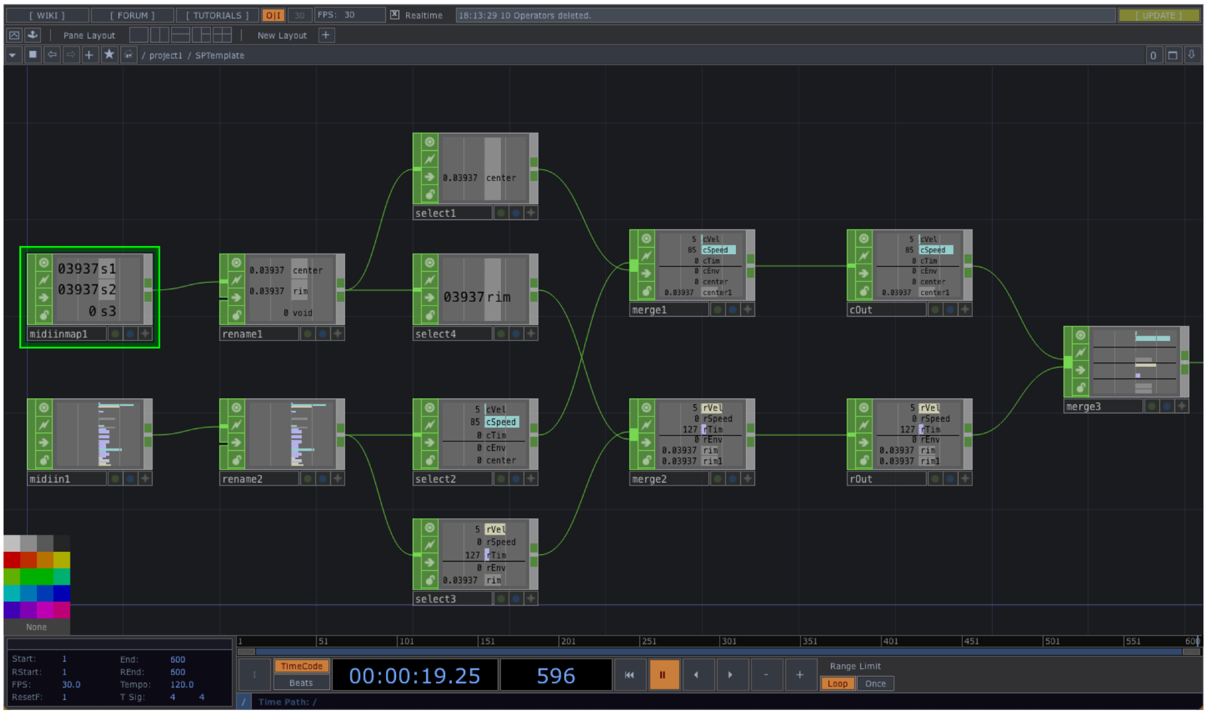

Figure 3.2: TouchDesigner/SensoryPercussion Template network. The top left is the beginning of the note message chain, the bottom left is the beginning of the CC message chain.

Once properly assigned within TouchDesigner, a considerable amount of programming is required before the data can be made useful. Because of this, I rely on a variety of templates to quickly parse the MIDI data coming from Sensory[31]. As is shown in fig. 3.2, TouchDesigner treats MIDI note and CC messages differently and thus their data points need to originate from separate nodal points in the network, or "operators" as they are called in TouchDesigner. Note messages originate from the "MIDIinMap" operator as they are sent through the mapped sensor, while the "MIDIin" operator handles the CC messages over the internal MIDI channels.

Once separated by message type, the channels are renamed for ease of use and then divided by region. In the case of the CC messages, all the data pertaining to controllers mapped to the "center" region are selected and parsed separately from all data pertaining to controllers

[31] visit https://github.com/mmmmjjjjjjjj/TD-SP-Templates to download these templates for free

mapped to the "rim" region, while note messages are separated appropriately from each other. Reducing the amount of primary regions in Sensory to "center" and "rim" in this MIDI mapping means that only two note messages are in play, with a third added if the "void" region is in use. Nevertheless, they are separated based on their materiality and merged with their respective CC messages, as seen in the second to last operators of each chain in fig. 3.2, before being sent out of the template.

3.2 "Everyday Durations" - Event-Time and Global-Time

Figure 3.3: Results of working with Sensory Percussion and TouchDesigner in three stills from "Everyday Durations"

Moving images and sound both share the element of being time-based media, so there is a certain fluency in the simple shaping of events that drummers bring to visual interactions. Working in TouchDesigner has allowed for the development of a growing body of interactive visual works that offer a drummer the opportunity to express rhythm in a completely new way. Concerns of dynamics, pacing, and of course composition apply just as much to a moving visual as they do to a piece of music. Through Sensory Percussion, a drummer can explore these relationships visually through the same practiced behavior that goes into the execution of a drum roll. "Everyday Durations" is a video work that represents these explorations in marking the passage of time across media.

Based on the 10Print pattern and early computer visual program[32], "Everyday Durations" is a piece that pushes this expression of rhythm and time itself. Each new notch is

[32] N. Montfort et al., *10 PRINT CHR$(205.5+RND(1)); : GOTO 10*, Software Studies (MIT Press, 2012).

advanced one square unit in the design as triggered by hitting the "center" region, and its angle is determined by the timbral controller of "center-to-edge". In this case, "center" hits result in a more vertical notch while "edge" hits result in an angled notch. The brightness of each notch is determined by the velocity of "center" hits and their color is determined by using velocity hits to select a random color value. A large amount of expressive possibilities in this piece are found in the speed controller, as the velocity controller is more in charge of the pacing of how the design moves through the grid. With its threshold set high, the speed controller is set to only respond to the most rapid-fire buzz rolls and ignore everything below 800 bpm. When activated, the speed controller can draw several additional notches on the design before moving onto the next space in the grid. Faster playing essentially results in a more static drawing.

The development of this piece follows a methodology for interactive visual works, which is the relationship between events and their structure. While TouchDesigner and Sensory Percussion can work together to visually articulate drum gestures in exciting new ways, it is much more challenging to translate the structure of a piece of music in TouchDesigner. Thus a contrasting relationship between controllers is helpful. In this case, velocity and speed controllers are almost working opposite to each other, where slower notes will advance the design and faster notes will halt its forward movement and cause it to spin in place. The patient teasing out of this relationship can yield significant tension and release compared to a simple one-to-one sound/visual relationship. Yet they are not mutually exclusive - combining one-to-one relationships, as this piece does with velocity and brightness, with more oblique or inverse relationships like speed and image location, result in a control over event-time and global-time in the piece.

3.2.1 Martial Time On The Snare

"Everyday Durations" relies on a single sensor configuration with a single mesh drum. For a person trained in drum set technique, this instrumentation foregrounds the snare drum and its attendant technique. The snare drum has more method books devoted to the study of it than any other part of the drum kit, and snare drum rudiments (or small repetitive patterns dependent on specific stickings) make up the bulk of a drummer's technical vocabulary between their hands. These rudiments are the thread of drum set technique that connect it most directly to a military tradition, as drum rudiments were developed by Swiss mercenaries as a way to keep large troops of soldiers coordinated. The marching rhythm of the snare drum and its technique suggest the forward march of time itself. When combined with the other instruments and full body coordination required of the drum set, this technique becomes a foundation for rhythmic interdependence and dexterous extemporizations. When limited to a single snare drum, the rudimental foundation in one's technique, if it has been established, is naturally drawn out. Thus, the instrumentation for this piece effectively suggests a playing technique that supports the aforementioned forward march of time.

This piece serves as a record of time passed much in the same way that the rhythms played to create these images can be considered to mark time passing (e.g. the dominant function of drummers in popular music styles as "timekeeper"). But whereas sound is useful for marking time (e.g., church bells, the ticking of an analog clock with a second hand, our morning alarms), it is ultimately too abstract a way to *record* time. Working with Sensory Percussion in tandem with TouchDesigner and other visual programming environments allows for the expression of events in time in an immediate and intuitively familiar way. When paired with new visual information such as the notches of the 10Print-inspired pattern, the experience of an amount of time being tallied or counted is unavoidable.

3.2.2 Speculative Interactive Duo with Kai-Luen Liang

The use of Sensory Percussion as an input source for interactive visuals was of interest to me before I had the skills in TouchDesigner needed to make works like "Everyday Durations". As such, I sought out a collaboration that would allow for what was then a purely speculative type of audiovisual interaction. Kai-Luen Liang (MFA 2020, Music Technology) is an advanced visual programmer who shared my interest in this method of collaboration. This duo was able to begin research on this collaborative method in February 2020 before the COVID-19 pandemic halted this workflow. Fig. 3.1 is a still image from one of these sessions.

3.3 A Linked Duo

Figure 3.4: “ * : ·° ” for linked duo with Isaac Rohr, in performance at Roy O. Disney Music Hall, California Institute of the Arts, Valencia, CA, February 8, 2020

Sensory Percussion enables someone playing the drums to tap into previously unimaginable varieties of expression. Because of the software’s learning curve that (practically speaking) must be tackled alone, the first applications of this technology by myself and many others have been to develop works for solo performance. However, just as the drums were never meant to be played without accompaniment (even if the accompaniment is simply another drum or drums), Sensory’s capabilities in enhancing the possibilities of collaboration are where a truly new artistic realm exists, and are where the link between a person and technology for new forms of creative expression can be expanded.

One limitation of working with Sensory is that by introducing an electronic music paradigm to drumming, one can start to feel a hindrance in the mechanical preoccupation of both hands that drumming requires compared to the truly limitless possibilities that electronic music production offers. While it is an incredibly expressive system, those expressive controls can *only* be accessed through drumming and need to be mapped beforehand. “On the fly” changes that radically alter the sound are simply not feasible, other than changing the entire kit to a radically different but also carefully pre-designed kit. Spontaneously changing one's sound in a way that is *indeterminate* is nearly impossible within Sensory Percussion's near-limitless boundaries. This energy coupled with continued efforts started in "Keep Time Keep Sake" to separate sound from source and led to the establishment of a collaboration where spontaneity and obfuscation were the stock in trade.

This collaboration was in a duo with Isaac Rohr (CalArts MFA 2020, ESP-Composition). Our collaboration was sparked by discovering a shared affinity for a niche subgenre of electronic music known as Breakcore, which was based on break-beats such as the "Amen" break played at extreme speeds and decibel levels. After continued discussions about electronic music and its culture, it became apparent that a collaboration between us would be necessary. Initial sessions had us running our signals in parallel, each sending our signals to a separate track on a mixer and playing in related simultaneity. Eventually we realized that there could be a way to send a signal in *series*, where my playing fed into the sound engine controlled in real time by Rohr.

The linked duo was made even easier by the introduction of a Sensory Percussion plugin for use with Ableton, which at the time was Isaac's preferred DAW. The timing of the introduction of this plugin by Sunhouse coincided with the very beginnings of this duo (the plugin was formally released in December 2020[33]) and required far less technical demands than our first attempts at a linked duo. The strength of the duo is in the way that it pairs our native instrumental fluency on our respective instruments with a shared resultant sound that leaves us each in equally partial control. The sounds themselves are shaped by live and in performance time by Isaac, while the events that trigger each sound are entirely determined by my playing. This is all done using one shared laptop with two persons controlling aspects of the sound, which can be a fruitful way to create interesting and surprising duo pieces using Sensory.

3.3.1 " * : ·° " - A Study in Causality and Obfuscation

This duo developed and performed a piece called " ** : ·°* " for the OK Composer series at CalArts in February of 2020. The piece provides an opportunity to further obfuscate the relationship between sound and source, not only for audience members but for the performers

[33] Sunhouse Staff, "Sensory Percussion 1.7," n.d., https://sunhou.se/blog/sensory-percussion-1_7/.

as well. It relies on an overall predetermined shape, beginning with complete obfuscation and ending with clear causality, but navigating from section to section relies on improvisation, and the quality of the improvisation depends on the musical dexterity in sharing, essentially, a single instrument.

The first section presents a maximalist introduction to the instrument space, where the drumming is as fast and dense as possible yet the resultant sound is a blur of high pitched, attack-less tones. As the section develops, the incidental acoustic elements of the drum kit, such as the sound of sticks on the rims, are introduced while a melodic pattern becomes more discernible. The second section relieves the tension of the dense first section through sparser rhythm as drum events and sonic events appear to become more causally linked. A third section introduces the main melodic loop through which all drum events are filtered as causality in this musical space is obscured and redefined. This section culminates in the original melodic theme of attack-less tones merging in the newly redefined drum-attack soundscape, the design of which was not predetermined. A denouement follows, as the soundscape grows sparser and causality is completely unobscured, resulting in a clear and total link between performers.

The shared partial control of either input or output creates a welcome disconnect for the participants where a new kind of telepathic connection is mediated by the DAW. Without fully being able to predict the sound quality one will get from hitting a drum, one cannot rely on muscle memory and must be fully engaged with the musical environment in order to make decisions on what to play. And without being able to determine the input events while composing in a DAW, one cannot fully sculpt and determine a piece of electronic music's course in time. Thus the participants must rely on a type of predictive listening, where musical context and the accumulation of each participant's gestures allows the other to make better decisions that support the whole.

The linked duo and predictive listening that arose from it can point the way towards new musical arrangements. While sharing pieces of a whole in a musical collaboration is nothing new, the way in which we did it offers a non-hierarchical method for making collaborative electronic music in real time. Furthermore, this is an electronic music collaboration that does not rely on a shared MIDI clock or otherwise electronically linked tempo. There is no "grid". This collaboration enables an exploration through time with electronic means that represents, perhaps, something genuinely new.

3.3.2 Speculative Interactive Trio with Kai-Luen Liang and Isaac Rohr

With these elemental duos in place, the idea to merge all three artists into one shared interaction was a natural next step. Through the aforementioned MIDI template and Ableton plugin, Sensory data was provided for Liang and Rohr to manipulate the visuals and sound, respectively. Much like the linked duo, this interaction type allowed each artist to focus on a single task, yet each artist only had partial control over the result of their individual efforts, by relinquishing control of timing for Liang and Rohr, or in resultant sonic or visual change, for myself. This group's work was based in improvisation, which enabled the artists to discover over time how their actions were influencing the whole. For the drum set, this work offered promising capabilities to immerse audiences in events of light and sound in an unprecedented way. This speculative trio assembled for one session and was requested to perform at the Outer Beast Festival at CalArts that was later cancelled due to the COVID-19 pandemic. As a result, no documentation of this group exists at present. However, the experience of assembling this group and having even the one interactive session has contributed significantly to my own practice of developing interactive multimedia works. Just like in solo work, approaching things with a methodology can yield more significant results and certain aspects of a methodology for interactive works began to arise after this one session.

Chapter 4

A Discussion of Temporality: The SOFT Glass

Expressions of musical timing are of course the bread and butter of all drummers. However, such a physically demanding instrument causes many to focus on the aspects of the instrument that are the most physically demanding, such as speed and velocity of attack. In a society that objectifies virtuosity and prodigious talent, it's only natural for many to assume that if they want to leave their mark on the world as a drummer, they'd better learn how to play lots of notes while being able to twirl their sticks above their heads (while not intended as a judgement towards drummers who have spent time practicing their speed, endurance, and stick twirls, I do not spare judgement on a capitalist music industry that urges drummers to think this way). But if a drummer wants to embrace the social nature of the drum[34] and work with other musicians, their success or failure is ultimately dependent on how they perceive time and how they express that perception in relation to their fellow musicians. Subtle differences in this perception from person to person make up what can be considered a drummer's sense of "feel" The language of musical time, as something distinct from clock time or "absolute time", includes all kinds of

[34] Jesse Ruskin, "Talking Drums In Los Angeles: Brokering Culture in an American Metropolis," *Black Music Research Journal* 31, no. 1 (2011): 85–103.

abstract terms like "groove" and "feel" that drummers must internalize and express even if they can't themselves articulate these same terms[35] [36].

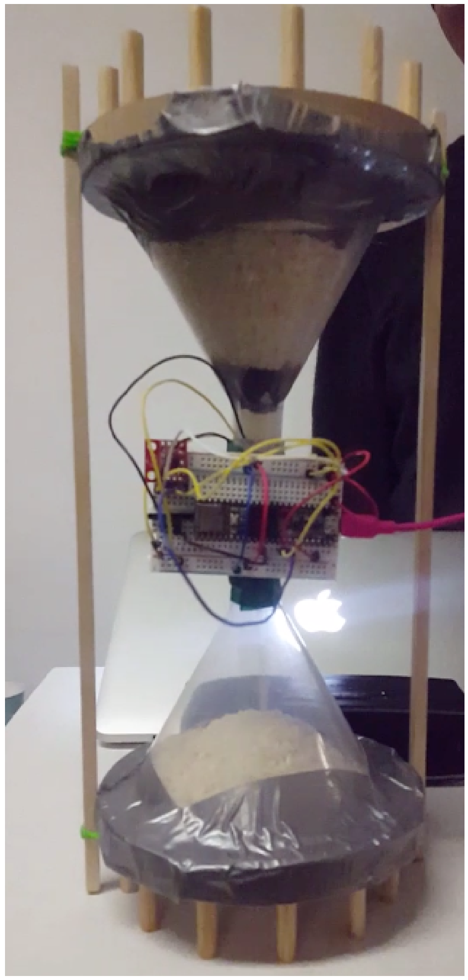

Figure 4.1: SOFTglass V1

In the majority of work presented thus far, the drum set functions as an input source for sonic and visual elements through which aspects of musical time are explored in ways that are grounded in the instrument and its timekeeping conventions, through repetitive rhythms ("Motus"), exploring causal links between gesture and sound (" * : ·̊ ", "Keep Time Keep Sake"), or visually expanding on the durational time-marking function of drum rudiments ("Everyday Durations"). Each of these pieces are indebted to some fundamental aspect of drumming while they circle around aspects of time keeping, memory, musical time, and the like. In order to explore these ideas as distinct from their relationship to drumming, a more direct

[35] Jonathan D. Kramer, *The Time of Music: New Meanings, New Temporalities, New Listening Strategies* (New York : London: Schirmer Books ; Collier Macmillan Publishers, 1988).
[36] Andrew V. Frane, "Swing Rhythm in Classic Drum Breaks From Hip-Hop's Breakbeat Canon," *Music Perception: An Interdisciplinary Journal* 34, no. 3 (2017): 291–302.

approach was undertaken in the form of a New Instrument for Musical Expression (NIME) that uses a timepiece as an interface.

The resultant piece is an interactive musical hourglass that can be manipulated for musical expression as well as to sonify the passage of time. Using a combination of infrared sensors, an inertial measurement unit, load cell sensors, piezos, and audio and digital signal processing onboard the circuit, the design allows for the passage and accumulation of grains to provide analog and digital input that can then be manipulated by changing the orientation of the hourglass. The first iteration functions as a MIDI controller while the second iteration has onboard amplification and synthesis.

4.1 Introduction

The earliest known hourglasses date to the 3rd century BCE, and they remain an enduring symbol for time passing, serving as the "waiting" cursor icon for Mac and Windows computers at separate points in their histories. While many of us may no longer have such analog timepieces in our homes, hourglasses are an elegant design object with an intuitive method of operation, which makes it ideal for both musical interface and art object.

Concurrently, improved connectivity of audio devices through Bluetooth technology has increasingly led to many of us inhabiting an ambient sonic environment that is largely set to our choosing, whether music, talk, or noise. An assortment of "smart" speakers, headsets, earbuds, and home stereo systems has made it possible to go about your day and have your sonic curations follow you wherever you are. And what to play? A growing industry around mindfulness has helped try to answer that by providing soothing soundscapes or guided meditations on apps like Calm and Headspace.

Perry R. Cook outlines several principles for designing a digital music instrument (DMI) in one of the first published NIME papers[37]. These principles have been hugely influential in subsequent DMIs that have appeared at NIME, yet the final principle seems oft-overlooked: "Everyday objects suggest amusing controllers". Perhaps the reason for this is a critical

[37] Perry Cook, "2001: Principles for Designing Computer Music Controllers," in *A NIME Reader*, ed. Alexander Refsum Jensenius and Michael J. Lyons, vol. 3, Current Research in Systematic Musicology (Cham: Springer International Publishing, 2017), 1–13, https://doi.org/10.1007/978-3-319-47214-0_1.

interrogation of novelty[38] and a push towards DMIs with longevity[39] within NIME over the intervening years. However, everyday household objects and objects otherwise not used for music making[40] have the potential to express and carry political meaning in a musical setting more directly[41], something that has become a concern within NIME.

By considering these seemingly disparate issues, that of the need for composers and performers to manipulate sound in real time without a keyboard or mouse, our increased seamless connectivity to our own sound curations, the political charge that household objects bring to a DMI, and the variable expression of musical time within an interface for synthesis control, I have developed a musical hourglass interface that can function as a tool for composers and performers as well as a timepiece for at-home use that marks the passage of absolute time through the eventual absence of musical time.

This paper presents the creation of the SOFT (Sonification Of Flowing Temporality) Glass, an interactive musical timepiece. First, in Section 2, related work from previous NIME proceedings is presented, with particular focus on DMIs that address musical time, physical modeling synthesis, and the politics of the everyday household object. Following this, the main fabrication, circuit design elements, and web-based model will be presented in Section 3. Section 4 details performance and composition practices based on the feedback provided by the instrument, and Section 5 concludes by proposing future implementations of the SOFT Glass.

4.2 Related Work

The NIME community is a space where digital music instrument (DMI) development has been untethered from commercial genre concerns, and there has been far more exploration in making expressive DMIs that address musical temporality than in the conventional musical instrument

[38] Fabio Morreale et al., "A NIME of the Times: Developing an Outward-Looking Political Agenda For This Community," n.d., 6.

[39] Fabio Morreale and Andrew McPherson, "Design for Longevity: Ongoing Use of Instruments from NIME 2010-14," *Proceedings of the International Conference on New Interfaces for Musical Expression*, June 1, 2017, 192--197, https://doi.org/10.5281/zenodo.1176218.

[40] margaret schedel, Jocelyn Ho, and Matthew Blessing, "Women's Labor: Creating NIMEs from Domestic Tools," *Proceedings of the International Conference on New Interfaces for Musical Expression*, June 1, 2019, 377--380, https://doi.org/10.5281/zenodo.3672729.

[41] Anna Rüst, "Bad Mother/Good Mother - an Audiovisual Performance," in *Music Proceedings of the International Conference on New Interfaces for Musical Expression* (NIME '19, Porto Alegre, Brazil, 2019), 8–10, https://www.nime.org/proceedings/2019/nime2019_music001.pdf.

space. In Sarah Reid's MIGSI[42], musical temporality is addressed directly by focusing on "how the independence between input and output can be utilized as a vehicle for exploring musical and performative time". Instead of needing to clarify and embody a role in the moment-to-moment creation of sounds, Reid goes the other direction, creating complex and oblique relationships between input and output through her mapping strategies. With the CD-Synth[43], Patrick Chwalek and Joe Paradiso present a method for addressing untethered rotation and orientation in a DMI, however the instrument design is essentially based on conventional keyboard elements like 12 steps and octave selection. It suggests manipulation of musical time for those that remember portable CD players, but the instrument does not ultimately engage with these ideas given its mapping of rotational speed to amplitude, rather than play rate. Lepri and McPherson suggest design principles based on utilizing objects from the past[44]. Through their use of a typewriter, they are able to use a DMI to merge conceptual histories across disciplines. The correlation between typewriters and synthesizers is most plain in the use of a keyboard. Piepenbrink's eShaker[45] [10] presents design considerations for using an imprecise musical gesture (shaker technique necessitates harnessing imprecise grains, as opposed to keyboard instrument technique that is based on playing a fixed array of keys, strings, and hammers). While the eShaker does not have any physical grains inside, the physical modeling synthesis contained within provided important guidance for the synthesis within SOFTglass.

While NIMEs have presented novel ways of exploring musical temporality and causality, sonifying the passage of time through various means have been in use for millenia. The use of an hourglass immediately calls to mind the family of instruments in the Shaken Idiophones or Rattles category in the Hornbostel-Sachs system of musical instrument categorization. This category includes the SOFT Glass' clearest predecessor, the Mapuche rainstick, which traces its origins to the Incas of Peru[46] and shares the same basic playing gesture of rotating the object about its axis 180° in order to send grains through the vessel. Another antecedent can be found

[42] Sarah Reid, Ryan Gaston, and Ajay Kapur, "Perspectives on Time: Performance Practice, Mapping Strategies, & Composition with MIGSI," n.d., 6.

[43] Patrick Chwalek and Joe Paradiso, "CD-Synth: A Rotating, Untethered, Digital Synthesizer," *Proceedings of the International Conference on New Interfaces for Musical Expression*, June 1, 2019, 371--374, https://doi.org/10.5281/zenodo.3672998.

[44] Giacomo Lepri and Andrew McPherson, "Mirroring the Past, from Typewriting to Interactive Art: An Approach to the Re-Design of a Vintage Technology," n.d., 6.

[45] Andrew Piepenbrink, "Embedded Digital Shakers: Handheld Physical Modeling Synthesizers," *Proceedings of the International Conference on New Interfaces for Musical Expression*, June 1, 2018, 362--363, https://doi.org/10.5281/zenodo.1302623.

[46] Gina Laczko, "Rainstick Origins" (Heard Museum, n.d.), https://www.watereducation.org/sites/main/files/file-attachments/rainstick_origins.pdf.

in the carillon, another idiophone that uses a keyboard to independently control at least 23 brass bells that are chromatically tuned and fixed in their suspension. This instrument, which stretches back to the 16th century in the low lying regions of northern Europe (Belgium, Netherlands, Luxembourg) built on the medieval uses of individual bells, which were for things like alerting people of church services or an impending invasion, and allowed for a musical exploration of such bells. Out of this came the tradition of church bells ringing a particular melody to signify the passing of an hour, a tradition still with us today(CITATION).

The use of a timekeeping device to sonify musical time also emphasizes the scarcity of time that affects us all, though some are more acutely aware of this than others. In Morreale et al., the authors suggest that "time poverty imposed by capitalist forces" is a potential reason non-musicians aren't able to transition to musicians, and that DMIs that can foster "instant music" (principle #6 of Cook's defining principles) don't always address the deeper reasons someone hasn't had the time or access to learning music. A musical hourglass at once makes instant music possible yet also raises awareness of universal "time poverty" by requiring little to no musical training for users to enjoy.

4.3 Implementation

This section describes the implementation of SOFTglass. Section 3.1 details the fabrication process and design considerations with respect to materials. Section 3.2 details the design of the overall circuitry as well as of the printed circuit board (PCB). Section 3.3 describes the motivation for the web-based model of SOFTglass, as well as programming and user-experience processes that contribute to the final physical version.

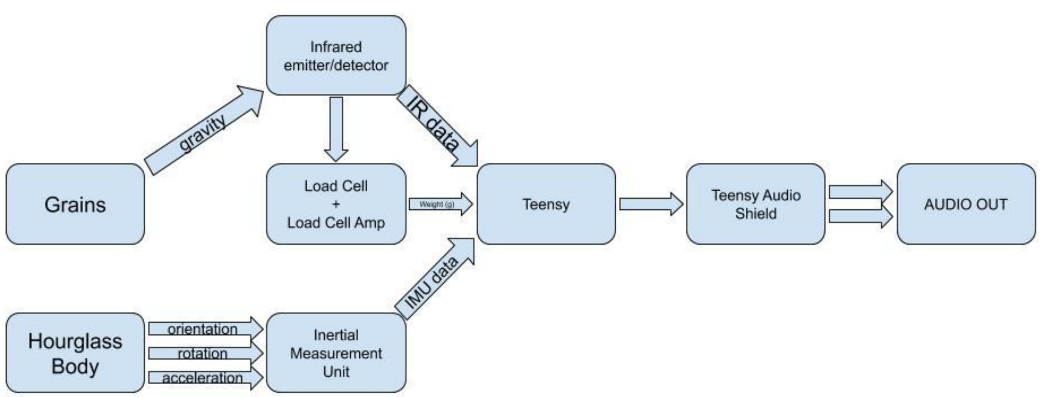

Figure 4.2: PCB flow diagram of SOFTglass V1

4.3.1 Fabrication

The SOFTglass V1 (fig. 4.1) is made using recycled plastic funnels fastened together using simple zip ties and plywood supports that keep weight and pressure evenly distributed. We felt that using recycled materials whenever possible is a more ethical and evocative approach, especially when sourcing electronics for DMIs can involve unethical supply chains and environmental practices.

4.3.2 Circuit Design

The PCB (fig. 4.2) contains a Teensy 3.5 with a 32 bit 120 MHz ARM Cortex-M4 processor with floating point unit (FPU) as its central processor. It has an MPU-9250 inertial measurement unit (IMU) for measuring movement, rotation, and orientation, each of which are mapped to separate musical functions in the Teensy Audio Shield protocol.

The first version of the project used a Teensy 3.5 for its quick connectivity with a DAW (Ableton) using the MIDI protocol for digital signal processing and data mapping, however the SOFTglass was always meant to be a standalone object. It uses an infrared emitter and detector pair, and in V2 will include load cell sensors (TAL220B) with amplifier (HX711) and piezo sensors to amplify the original acoustic sound made by the grains in the hourglass chamber. In addition to the Teensy Audio Shield, two 4 Ω 3W speakers are driven with a Stereo 3.7W Class D Audio Amplifier (MAX98306).

The PCB is powered with the Power Boost 1000 Charger. While powering the circuit sufficiently, this gives us the flexibility to work towards eventual portability with an on-board lithium ion battery. The current iteration requires power via Teensy's USB micro-B port.

4.3.3 Visualization of SOFTweb

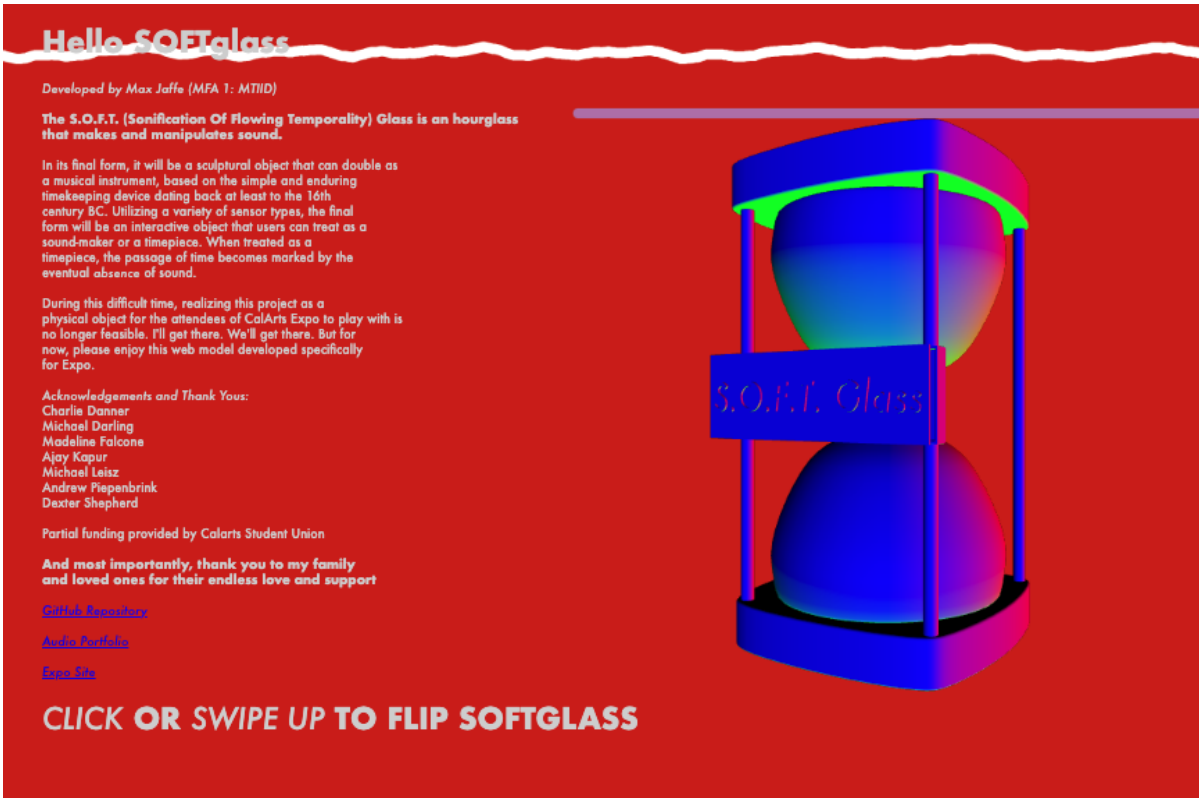

Figure 4.3: SOFTglass homepage

The initial ideation and development phase for the SOFTglass took place during the fall of 2019. Production was halted due to the COVID-19 pandemic that closed access to the California Institute of the Arts' campus and most other public spaces in the U.S. in March 2020. As a result, there was a forced reconsideration of how to share the first step in the development of this DMI. Creating a web model (https://thesoftglass.com/) became an essential part of realizing this project as sound design and user experience elements required careful consideration in order to create an effective simulation.

The site (fig. 4.3) is programmed using the p5.js programming language and features key elements that mimic the functionality of the SOFTglass in its physical form. When the user clicks on the page, the 3D object (taken from the CAD design) flips over its horizontal axis and the sound file begins playing, mimicking the same start/stop gesture that the real object uses. The playing of the audio file is represented visually in multiple ways: 1) a line whose position in the browser window corresponds to the current time in the file, 2) this same line's width corresponding to the root mean square (RMS) value of the waveform, and 3) a line drawn with greyscale according to intensity at each frequency according to the Fast Fourier Transform (FFT) value of the waveform. The file is played forward or in reverse, depending on the orientation of the 3D object.

Developing this project for the web helped clarify multiple design elements. The start and stop functions were mapped to the orientation of the object, and when coupled with the direction the audio file is played, this gives the web model an instant "playable" feature, however simple. Bringing immediacy and "instant music" to the web model helped to solidify how the next iteration of the physical instrument would function.

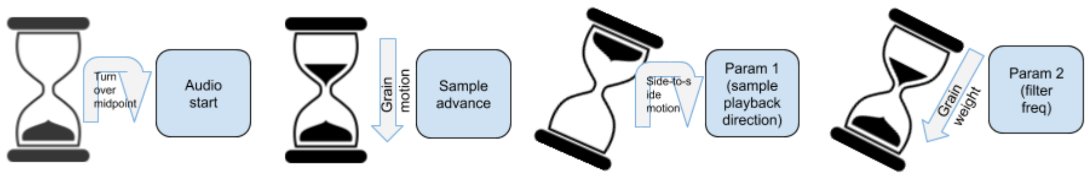

Figure 4.4: SOFTglass v1 user interaction diagram

4.4 Performance & Composition

In the first iteration, each half rotation of the body about its Z axis begins the audio player, while each IR detection event advances a playhead through a sample at audio rate. The SOFTglass can detect when the object is rotated/turned over, as well as the passage and accumulated weight of grains. These data sets are mapped to sound parameters of the composer's choosing using the Teensy Audio Shield integrated development environment (IDE). It amplifies the acoustic sound of the grains of rice within using piezo sensors, which are added to V2. Much of the time spent fabricating V1 was actually on how to get a smooth flow of the grains inside. The grains (rice, in V1) were prone to getting stuck and not flowing. In performance or on display, this continues to be a concern. However, the audio would respond to the lack of data passing through the IR, which means design considerations to V2 focus on improving the physical flow of grains rather than the signal flow, which works effectively. V2 uses a bigger vessel to allow for more motion of the grains and greater physicality in performance.

From performance instrument to meditation timer, from installation piece to productivity aid, the SOFTglass has numerous applications for musicians and non-musicians alike. Version 2.0 includes piezo sensors and a larger body. A 3D printed encasement for the

PCB has been designed and will be the centerpiece of the next iteration. Through the inclusion of an SD card, composers should be able to design and upload their own sounds and making additional SOFTglasses for other composers will be imperative to improving its design.

4.5 Conclusion

The SOFTglass was built to be a musical hourglass that could function as a playable instrument as well as a sculptural timepiece that marks time with the *absence* of sound. The ideation and development of the SOFTglass was borne of two distinct impulses. One was to develop a novel NIME that would allow for a musical interaction that didn't require any specific instrumental technique to play. The second and more pertinent impulse was to make a novel NIME that would connect with my work as a drummer and that would allow for musical explorations of time cycles and rhythms in a simultaneously more literal and more abstracted method. In considering the musical time-keeping function of drummers, as much of the work described in chapters 2 and 3 does, ideating a musical timepiece was not as significant of a leap for a drummer looking to make meaningful contributions in the NIME community as it might appear on the surface. While drummers' livelihoods can be determined by their ability to reliably "keep time", a clock's usefulness is determined by the same ability. In both realms, a shift towards digital timing has become the dominant preference but these shifts have made the "analog" methods, like vintage drumsets and grandfather clocks, increasingly rarified expressions of human ingenuity and achievement.

Future work will pertain to the fabrication of a more stable body for the hourglass and PCB, a more robust set of mapped controls using the Teensy Audio IDE, and sound design and composition for the musical aspects of the device itself. An original performance piece for drum set and SOFTglass was part of the initial ideation phase and will be further developed for the second iteration. In addition, the development of the web version of the SOFTglass has led to my development of additional web spaces that have a limited set of musical interactions. There is great potential in using p5.js to invite musical play online, suggested by the web version of the SOFTglass.

Chapter 5

Conclusions

5.1 Summary

The primary goal of this thesis is to establish a historical continuum between drummers and music technologists to which future generations may contribute using a proposed methodology for working with Sensory Percussion sensors. The collection of instruments that make up the drum set may be technologically simple, yet within this straightforward interface that has experienced minimal design changes in its history, drummers have continually expanded the range of possible techniques used to play the instrument. The expansion of these technical possibilities have partly been driven by the history of recording and audio fidelity, as improvements in music technology have significantly impacted the ability of each generation's cohort of mature drummers to express their ideas with greater sonic clarity and wider listener reach. This has made it possible for each generation's cohort of *student* drummers to study from an ever-broadening range of highly detailed drum set recordings from across genres and historical eras. The cycle perpetuates by the time those drummers embrace newer technical possibilities, as *technological* possibilities have often kept pace.

While recording technology has contributed significantly to the development of drumming technique, the musical function and sound of drumming has provided inspiration for music technologists less concerned with faithfully recording the sound of drums and more with synthesizing, sampling, or analyzing them. Early attempts at synthesizing drum sounds by technologists at research laboratories laid the groundwork for the widespread use of drum machines and electronic drums, while early manipulation of magnetic tape eventually led to sampling. Increases in personal computing power not only led to increased availability of synthesis and sampling, but also increased frequency analysis possibilities. Through expanded possibilities for analysis, timbral recognition and physical convolution emerged as two fundamental developments in the analysis of drum data on which the Sensory Percussion system relies.

Sensory Percussion allows a drummer to use their instrument as a way to access the techniques of sampling and synthesis that were previously unavailable from behind the drums. Contemporary electronic music often relies on a metronomic grid that lacks the slight imperfections in human drumming that are actually responsible for the unique sense of "feel" that each drummer brings to the instrument. By using Sensory, a drummer may merge contemporary electronic sound production techniques with a human feel that is freed from a tyrannic grid. This thesis contains a body of work for solo drum set with Sensory Percussion that not only frees electronic sound from a mechanized grid, but also frees the gesture of drumming itself from its sound.

Furthermore, Sensory Percussion enables a drummer to merge their human rhythmic feel with extra-musical elements, as is the case in my work with TouchDesigner and 3D graphics. The possibilities of unique collaborative formations using Sensory are plentiful, as it can communicate over the MIDI protocol with any other MIDI-enabled device or software. Audio signal from Sensory can easily be shared and processed as well to create a shared instrument space for two or more performers. However, the release (during a crucial phase of research for this thesis in November 2019) of a Sensory Percussion plug-in for Ableton has enabled the creation of such a shared instrument with significantly more ease than signal processing.

Much of this work allows for an exploration in time as a fundamental component of music, like sound, to be freely manipulated. In order to engage with concepts unique to this work, a new instrument for musical expression (NIME) has been developed and presented. This NIME is based on the design of an hourglass timepiece and urges people to engage with temporality in a physical and musical sense. Future iterations of the hourglass NIME are proposed, as well as additional collaborative configurations and solo works.

5.2 Primary Contributions

As an early adopter of Sensory Percussion, I have developed a body of solo and collaborative work that uses the drum set as an input device for a broad range of samplers and visual effects, unlinks causality between the gesture and sound of drumming, and reframes the drum set's relationship to absolute and musical timing. Through the development of this work, a personal set of reliable methodologies and strategies have emerged that help close the gap in Sensory Percussion between technical and creative work. The set of methodologies described are:

1.) *Materiality*: hitting a drum with a stick requires three materials with resonant properties - plastic (drumhead), wood (stick and possibly shell), and metal (hardware and possibly shell). Does your drum model *really* need 10 different samples being triggered? Consider the drum.

2.) *Intentional pitch ranging*: Controlling the playback speed, and thus pitch, of a sample with velocity can be very effective for controlling pitched elements. However, unless the range is quantized and limited, this type of melodic control is unwieldy. Small quantization options with large ranges can be effective for creating a drum that can function as a slowed-down bass element with low velocity hits and a sped-up percussive element with high velocity hits.

3.) *Meaningful Sampling*: sourcing samples with specificity brings specificity to the music. This applies most directly to when using samples of the human voice. If the sample isn't a human voice, perhaps it came from making field recordings somewhere personally significant, or was made and shared by a friend as a sort of commission for a piece. Even if just for the drummer, this meaning works its way into the music.

4.) *Generative Drumming*: the internal LFO can be used as a way to independently control effects, such as by creating one at 0.01 Hz and assigning it to slowly change the mix level on a delay, for example. More importantly, it can be assigned to *play* regions of a drum - when using metrically related LFOs, it is possible to create a field of generative polyrhythmic impulses to be applied to samples of one's choosing (hopefully ones that have been meaningfully sourced!).

5.) *MIDI Mapping in TouchDesigner*: through use of customized data parsing templates[47], the drums can be used as input and control for manipulating visual elements in the visual programming software TouchDesigner.

6.) *Causality*: A one-to-one visual and sound connection is just a starting point. Contrasting gestures with their result, whether visual or sonic, can be a useful way to approach the development or structure of a piece.

These methodologies are personal and by no means comprehensive or prescriptive. There are many aspects of designing kits that this document does not approach, largely because they have either been documented by Sunhouse in their tutorials[48] or because they veer into the realm of audio engineering and production, two fields that are also well documented. These are methodologies that are beyond the scope of existing documentation in the field of drumming with sensor technology and have arisen from developing my own body of work with certain approaches consistently revealing their use. It is my hope that these methodologies, while derived from personal work, are broad enough to assist any other drummer working in this system.

5.3 Other Discussions: Creative Actualization with Sensory Percussion

With these methodologies in place, a certain fluency in using Sensory Percussion to develop a body of work has arisen. This fluency has brought with it an ability to explore extra-musical ideas related to the drum set, such as temporality in music. While my journey with music began with the drum set, using Sensory Percussion enabled me to engage more deeply with ideas that had been percolating internally for years, to the point that it became feasible to extrapolate on these ideas apart from the drum set in the form of the SOFTglass. Learning how to use Sensory Percussion is not entirely responsible for the creation of the SOFTglass, but it is energetically responsible for jump-starting a technological curiosity that began with the drums.

5.3.1 Augmented Drumming: A New Genre?

There is significant potential for this system to allow for a new genre of augmented drumming that allows drummers to express rhythmic ideas in tandem with extra-musical ideas they are

[47]Visit https://github.com/mmmmjjjjjjjj/TD-SP-Templates for downloads of these templates.

[48] https://sunhou.se/blog/tags/tutorials/

most passionate about. The chance to further shift the paradigm of the drumset and expand on its musical function means more and more drummers may be empowered to use this system as a path to more meaningful creative expression and a deeper sense of their creative "feel". Drummers like Ian Chang[49], Greg Fox[50], Val Jeanty[51], and Eli Keszler[52] have begun to use Sensory to develop solo records, trigger visual media in performances, and control modular synthesizers to lay the foundation for a new style of drumming. However, as we saw in chapter 1, every meaningful playing style is associated with a genre of music. As such, drummers working in Sensory are potentially building a new genre of music as well as a new style of drumming.

5.4 Final Thoughts

As is the case with recording technology's impact on drumming, the impact that Sensory Percussion could have on the next generation of drummers is exciting to consider. One safe prediction is that the relationship between recorded music and drummers and its influence on drum technique will continue unabated, and will increasingly reflect the increased mechanization of music and the particular popularity of electronic dance music forms in the pop music sphere.

A riskier prediction imagines the impact of a generation of drummers who have practiced a form of creative actualization through Sensory Percussion. As drummers embrace this system, they are enriching their understanding of production techniques and composition, but also must engage in a deeper dialogue with their own creative ideas in order to compose original works for this system in a way that is personal and, ideally, compelling to listen to. It's not hard to imagine a future generation of drummers who resonate with the drum set as a tool for the innate human experience of musical expression and who are equally motivated to use the drum set as a tool for augmented self-actualization through electronic media. The landscape of contemporary music at this point may be near unrecognizable, in a way that should excite creative musicians and technologists.

Are drummers ready to embrace a version of self-actualization through music that involves working so much with technology? An instrument that operates with such simplicity as a drum has shown itself to barely need improvement, and those devoted to drumming may find

[49] *Ian Chang - Spiritual Leader*, 2016, https://www.youtube.com/watch?v=CS7rDZhcHL0
[50] "Greg Fox Bandcamp," n.d., https://gregfox.bandcamp.com/
[51] "Val Jeanty Soundcloud," n.d., https://soundcloud.com/vjeanty
[52] "Eli Keszler Webpage," n.d., http://www.elikeszler.com/

it a challenge to make time for mastering this technology while mastering the drum set is enough to occupy one's entire lifework. However, drummers have proven themselves to deal with more gear than anyone else in the band, so perhaps adding sensors to their gear case is not a stretch. Additionally, drummers have the unfortunate distinction of having a whole genre of jokes written at their expense, all attacking their perceived intelligence no doubt due to the similarities between (especially) rock drumming and repetitive manual labor (what with all that heavy gear to lift). Some drummers may even internalize these beliefs and feel that working with sensor technology is beyond their capabilities. But these jokes touch on a potential insecurity on the part of the joke-writers that everyone in the band may be aware of - that the various methods of mental and physical coordination required to use four limbs to play an array of membranophones and idiophones can actually be "an expression of intrinsic problem-solving abilities"[53].

Beyond being able to solve the technological problems that Sensory can present, what does it mean for a drummer to pursue a path to creative actualization through music that is reliant on technology for its creation? Working with Sensory can sometimes cause what feels like a new neural pathway in the brain to form, where a piece's specific set of controls, events, and gestures are overlaid on top of drumming, a learned behavior that becomes instinctual with practice. In the development and performance of a set of deeply personal music, navigating the controls, events, and gestures with learned behavior can lead to a connection between mind, body, and emotion that each piece conjures in particular ways. Doing this with technology may seem antithetical to drumming on its face. In fact, I see it as a natural evolution of a process that has always been informed by technology.

5.5 Future Work

The main result of the work presented herein is a facility with composing for Sensory Percussion and for extending its use in two directions. One direction will be towards further development of visual pieces that use Sensory in tandem with TouchDesigner. Visual programs that highlight or ambiguate the drumming used to control it will be continued in the style of "Everyday Durations", and I am developing a long-duration performance piece that will have an accompanying TouchDesigner network. Additionally, TouchDesigner can be used to parse MIDI

[53] https://consequence.net/2015/10/its-official-drummers-are-smarter-than-you-and-everybody-else/

data that is then sent to external visual objects such as lights or monitors. As part of the speculative duo with Kai-Luen Liang, a project was in development that would use Sensory+TouchDesigner with an array of cathode ray tube (CRT) monitors, externalizing the control of visual events. This project will be continued when restrictions due to COVID-19 have been lifted.

The other direction to explore with further work will be towards new methods of interaction and collaboration with Sensory. The possibilities represented through the Linked Duo are something that will be expanded upon through more compositions and performances. Beyond collaborative configurations already presented, I am interested in working directly with choreographers to explore the gesture of drumming through the perspective of prioritizing the gesture and not the sound. These are ideas I touched on in my solo work and I see the possibility to build on this with an artist who is dedicated to movement and gesture. The gesture of controlling such vast fields of sound with minimal effort subverts our expectations of a drummer's performance, and I imagine the collaborators that might be most intrigued by this come from dance, not music.

The SOFTglass will continue to figure prominently in my future work as well. A working prototype and web model have been important for realizing the concepts behind the instrument in an executable way. However, a second version that uses more stable materials and has all sound engines and speakers onboard has been planned. Continued sound design and composition for this project can contribute to my performance practice as well as to the NIME community.

The larger goal of this work has been to expand on the role and capabilities of the drum set and to position it within a technological paradigm of new artistic expression. As technology redefines drumming, we are encouraged to reconsider the role of the human in music. Drumming has ancient historical roots that connect us to our humankind ancestors, while machine learning, timbral recognition, and neural networks seem to offer a herald of an unknown but technologically-driven future. By connecting these threads in a body of work, I hope to bridge a perceived gap between "man and machine" that allows us, through music, to experience our truly symbiotic relationship with technology.

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