Physical Composition: The Musicality of Body Movement on Digital Musical Instruments

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by Jon Bellona

Abstract

Advancements in digital computing have allowed the amplification of the organic body as musical instrument. This dissertation explores human-computer musical interfaces (i.e., alternate controllers) through the view of the body and describes music composition using digital technology through physical movement. The dissertation aims to 1) develop a framework for body—digital technology—sound discourse and 2) describe a collection of software tools, digital musical instruments, and music that demonstrates this framework.

Chapter 1 frames alternate controller digital musical instruments around the body, and Chapter 2 looks at physical movement through its numerical representation inside the computer, discussing how the digital byproducts of movement help shape our musical choices. Chapter 3 describes software tools for aiding digital sound composition on digital musical instruments. Chapter 4 outlines a digital musical instrument composition and performance practice, and Chapter 5 builds from Baruch Spinoza, Shaun Gallagher, and Mark Johnson to dissolve mind and body divides in the act of composition on digital musical instruments. Chapter 6 further explores how the rich palette of body movement can become a musical voice with a report on a new musical instrument, Distance-X. The final chapter revisits a concept central to digital musical instruments, the movement of data, in order to describe how pre-existing digital information can be set into musical motion.

Working from the embrace of physical bodies inside our digital lens can help acknowledge the complex and different stories that make-up our musical communities. *Physical Composition* strives to address the concerns and the capacities of these bodies and endeavors to stand as a model for achieving symbiosis between performer and digital sound. This dissertation seeks to affirm physical resistance in a digital music practice and depict how Physical Composition is both an art of the moving body and an art of composing sound.

The dissertation is intended for PDF format and should be read from a digital device/software capable of accessing embedded links. Internal references to chapters, sections, subsections, and citations contain embedded links that jump to the appropriate section. All audio and video examples include a clickable icon that points to its online content. A complete list of audio and video example links is provided in the Appendix.

Acknowledgments

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This dissertation is dedicated to my late college advisor and computer music mentor, Dr. Samuel F. Pellman (1953–2017). There is so much more I wish I could sound out with you; your voice continues to echo outward, but the source of which will be forever missed.

We zoom into sound, and we do it through physical movement.
- Sensorband

I'm thinking four inches above my head.
- jpb

This doctoral dissertation has been examined by a Committee of the Department of Music as follows:

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Introduction

> The body is man's first and most natural instrument. Or more accurately, not to speak of instruments, man's first and most natural technical object, and at the same time his first technical means, is his body.
>
> Marcel Mauss (Mauss 1992, 461)

This dissertation is about working with digital electronic sound through the human body. A composer or performer, with the assistance of digital musical instruments, can touch and shape digital electronic sound in new and exciting ways. Instead of prescribing motion, digital musical instruments enable music composition to access the full, rich palette of human movement, crafting that movement into a musical voice. With the employment of digital technology, choreographed movement can become central to a musical process.

While acoustic instruments also require human movement, the aim of this dissertation is to unpack the creation of, the composing with, and the performance on digital musical instruments (DMIs) as musical processes. The activation of DMIs—their construction and their coding—creates a dialog between affordance and affect that locates the moving body inside the creation of live, digital music. The physical dialogue between performer, DMI, and sound is where this dissertation takes root. As the choreographer William Forsythe asks, "What else besides the body does physical thinking look like?" (Forsythe 2009). The social, technological, philosophical, and physiological ideas of body inform DMI practices, and this dissertation tackles coding and composition alongside corporeality, striving for a broader consideration of how we make and what we call digital music. Building from the musical practices of composer-performers like Michel Waisvisz, Laetitia Sonami, and Christian Marclay, among others, where the physical interaction with DMIs and electronic objects formulates a contemporary musical practice, this dissertation details a physically informed DMI musical practice as a method of music composition, a method I call *Physical Composition* (Chapter 5).

Physical Composition describes the active conversations between movement and sound among composer / performer / instrument carried out during the DMI composition process, and the practice stems from a personal history of building, composing, and performing on DMIs. Physical Composition can involve many fields, including: digital instrument building, sensor-to-sound software mapping, physical movement, music composition, choreography, music performance, and audio production. Because of the many areas through which Physical Composition traverses, the practice demands a holistic approach to digital music. Practically speaking, each new piece of music using Physical Composition requires knowledge of digital technologies, human movement, music theory, and sound design applications. While I have begun to apply the term outside of my own music composition work, Physical Composition will primarily be used herein to describe *alternate* controller DMI compositions and performance contexts. I capitalize the term throughout the dissertation in order to avoid possible confusion with other notions of these terms.

The focus of my research in DMIs is grounded in two main ideas. First, **human involvement in live performance commands a presence amid a dialogue between the music and the digital technology**. The emphasis on a dialogue among body, music, and technology places the human and their processes within the musical outcome rather than treating digital technology (e.g., sensors, connection speeds, learning algorithms, etc.) as the solution to musical performance. Performed movement on DMIs and their resultant digital sounds have meaningful but complex relationships—and not all of them are gestural. As Bob Ostertag notes, "the tension between body and machine in music, as in modern life itself, can only exist as an experience to examine and criticize and not as a problem to resolve" (Ostertag 2002, 11). Physical Composition is a messy process where body is intertwined with interface, virtuality, image, and sound. Moving is thinking in Physical Composition, and as will be underscored throughout the dissertation, physical thinking is necessary to realizing the full potential of a Physical Composition approach.

The second idea is that **the generation and use of data has changed the way we approach digital music**. The dissertation looks at physical movement through its numerical representation, digital data streams, and shows how these digital byproducts of movement help shape our musical choices. Not only are data for DMIs representative of human performers, their actions and their movements, but the choices surrounding data are colored by human factors. Some choices are deliberate and some are inherited (e.g., sensor-type, sensor-placement, sensor-conditioning), and how these factors interact with data can determine the flow of digital information that shapes the rest of our digital musical landscape.

Within the context of these two ideas and to help situate my own research, Chapter 1 looks at DMIs from a body perspective. I review previous authors' work on DMI categorization in order to describe alternative or "alternate" controllers, a small subset of DMIs (Miranda et al. 2006, 21). Alternate controllers serve as the instrumental focus of this dissertation, as it is through alternate controllers that I have been able to explore and extend a dialogue between kinesthetically rich body movement and sound.

Chapters 2 and 3 unpack the human traces in data. In the context of alternate controller DMIs, data is the instrumental extension of our performing bodies, and the thesis details how the body has become a body of data that drives musical systems. Chapter 4 presents analyses of a selection of DMI case studies, and frames a composition and performance practice on DMIs. The text examines how different digital interfaces affect the performance of musical works and outlines ten values of Physical Composition in the context of alternate controller performance. Chapter 5 discusses Physical Composition in further detail, outlining the how and why of digital musical movement and its rationale for being understood as part of a digital music composition process.

The music throughout the dissertation consists of works for various DMIs, in particular repertoire for a new alternate controller DMI, *Distance-X*, developed as part of the dissertation (Chapter 6). Works for Distance-X explore how the dialogue between motion and sound inform a composition practice, and demonstrate how slight alterations in software choices (e.g., mapping distance to pitch, amplitude, panning, etc.) drastically change the resultant sonic character. Other music in the dissertation will explore additional alterations within the body-sound discourse, namely the controller input (e.g., Wacom tablet, eMersion™ wearable technology); do-it-yourself (DIY) instruments, and the performers themselves. Each musical work in this dissertation employs custom software. Collectively, these works (music and software) reveal the vital, connective tissue between the moving body and digital sound.

The trajectory of my two underlying ideas—the importance of body and motion in dialogue with DMI composition; and the notion that crafting data has changed the way we approach digital music—leads toward a concluding statement about the movement of data, the idea that pre-existing digital information can be set into musical motion. Just as body movements become data that drive musical systems, so too can we activate 'motionless' data in order to move musical systems.

Irrespective of how we activate movement inside our music, the presence of physical bodies inside a digital music practice remains a human endeavor. Our recruitment of human performers within digital musics provides an opportunity to acknowledge the rich diversity of our musical stories and our capacity for telling them. Physical Composition is a willful attempt to leverage the physical resistance of the performer in digital music, and this dissertation ventures that physical resistance is a form of risk-taking that pushes us toward satisfying and meaningful musical rewards. Physical Composition is both an art of the moving body and an art of composing sound.

Chapter 1

Digital Musical Instruments: Movement into Data

> In the beginning art never referred to its own context, rather it arose from interest in the human being, who needed it for his rites and his religion.
>
> Marina Abramović (Abramović et al. 1998, 17)

Music has largely been a public and social act. Until the rise of recording technology, musical expression found its common ultimate form in live performance-events where performers communicated music to an audience. The nature of live performance traditionally involves the presence of bodies—listeners and performers—together in a space. The role of the human in the creation of music was clear: physical actions were required to produce sound.

Recording technology challenged the presence of performance by offering new modes of communication. Recording became not just a way to capture live performance, but took on an artistic practice and presence unto itself. This presence has been catalyzed by the rise of new technologies (e.g., multi-track recording, turntable), sound production techniques (e.g., delay, loop, re-amp) and technologically driven musical structures (e.g., concept album, 45 r.p.m. single).

Advancements in computing technology offered the ability to bring the sonic advancements of the recording studio back to the performance stage. Beyond traditional interfaces like the synthesizer and microphone, new digital musical instruments (DMIs), predicated on sensors and computers, gave humans the power to transmit musical ideas through alternative modes of the performing body. Digital computing in musical performance ushered in a groundbreaking transformation—the physical separation of action-to-sound relationships—and at the same time increased the capability of body signal (external movement / internal systems) as control signal. These countervailing technological mediations continue to present challenges and possibilities to the 21st century digital music composer and performer.

With the rise of alternate digital musical interfaces in the popular market and mainstream music genres, DMIs are becoming an attractive technology for musical expression.[1] For example, Marshall (2008) documents 266 new DMIs in just the first eight years of the New Interfaces for Musical Expression (NIME) conference. Situating alternate controller DMIs in this first chapter will help outline performer-instrument relationships and silhouette the body that stands in dialogue between digital musical instrument and digital electronic sound.

1.1 Definition

A digital musical instrument (DMI) describes a musical instrument that, in some part, depends upon digital computing. Yet, digital computing broadly defines what a DMI actually consists of. Miranda and Wanderley (2006, 21), and later Tanaka (2010),[2] outline a DMI as consisting of three main components:

- input [sensor(s)]
- mapping
- output [sound]

While this breakdown appears as a gross simplification, many have outlined performer-instrument feedback systems similarly, including Bongers (2000) and M. Wanderley (2001). Marshall (2008) combines these two models together, keeping the input-mapping-output as part of his combined model (26).

[1]Tim Exile, "2016: The Year Music Woke Up," *Medium*, January 25, 2016. https://medium.com/cuepoint/2016-the-year-music-woke-up-63a66b2af73#.872tawko0 (accessed March 1, 2018)

[2]Atau Tanaka identifies five components in "Open-Ended Systems" (Tanaka 2009). Later, Tanaka cites Miranda and Wanderley for his DMI definition, which consists of the three components listed above (Tanaka 2010).

Input [sensor(s)] represent the conversion of a physical input (e.g., button press, rotation angle, heart rate) into a digital signal.[3] Digital signals, then, may be thought of as performance data, typically outlining the physical actions of the performer, however substantial or slight the physical action, and however coarse or fine the resolution of the digital signal. A common input signal path includes the performer's physical movements, hardware sensors, analog-digital-converter (ADC), and computer input (e.g., USB). Connections speeds may affect DMIs, and Pennycook (1985) describes how timing corresponds to the "streaming of performance data" within the signal path (269).

Mapping represents the connection of digital inputs to sound synthesis parameters, and various mapping strategies for creating and assigning these connections have been discussed by many. Rovan et al. (1997) and Hunt, M. Wanderley, and Kirk (2000) introduce different mapping types; Bevilacqua et al. (2005) describe interpolation mapping problems; Schedel et al. (2011) apply machine learning techniques toward mapping as a musical application; and Sinclair et al. (2010) outline custom software, *libmapper*, for mapping sensor inputs to software outputs.

Output [sound] in the DMI model typically represents the digital musical instrument's sound synthesis engine. That is, DMIs usually employ digital sound synthesis with sound production via loudspeakers. Of course, any digital output can be split and/or routed back into any digital input for additional parametric mapping or connected to any type of physical actuator (for examples, see Chapter 7). A common output signal path includes digital sound synthesis, digital-audio-converter (DAC), and loudspeakers.

1.2 Performer-Instrument Shifts

An acoustic instrument requires the body to interact with its instrumental interface. "The instrument is a form of interface through which sound is produced, a prosthetic to physical presence" (LaBelle 2006, 270). Digital musical instruments challenge the role of the body as digital technology profoundly changes the relationship between performer and instrument. The performer-

[3] The inputs of a DMI are digitally input to its computer. Any electrical signal involves an analog-to-digital conversion (ADC).

instrument relationship is altered in three ways by DMIs.

First, sound-movement relationships may not be known prior to performance. For performers playing the instrument or for audience members seeing an instrument for the first time, the controls and resulting sounds of a DMI may be unfamiliar. The cultural knowledge of an object-as-interface may challenge both performer and audience in terms of the instrument's newness or the instrument's re-appropriation of an existing object with a known alternate function. Some, like Calegario, Barbosa, et al. (2013), leverage the exploration of sound-movement relationships within their framework for building new DMIs. Conversely, embedded sound-movement relationships on alternate controller DMIs may stand in opposition to preformed conceptions of movement and sound relationships. For example, moving down, or left, on an alternate controller DMI may raise the pitch, which is contrary to common conception (Eitan and Granot 2006, 224). A final point to make here is that musically-identified objects are not the only things that can produce sound (Hardjowirogo 2016). For example, Sensorband's *Soundnet* transforms the tension of shipping rope altered by performer's movements into musical sound (Tanaka 2000). Because of these sound-movement factors, the alternate controller DMI may need to establish new sound-movement interactions within the music.

The second shift to performer-instruments via DMIs is that sound-movement relationships may change within a short period of time (between works or within a single work), meaning that no established sound-movement relationships are safe. Even when played on the same DMI, sound-actions may shift from within the same piece (e.g., section to section) because of the ease with which digital technology may change control states. For example, Michel Waisvisz altered control states on The Hands frequently (Bellona 2017). For additional examples of shifting sound-actions, see Chapter 4.

Lastly, DMIs enhance the power to manipulate information (e.g., sound), ceding powers of physical control over to technological functions. In most cases, the performer's physical actions are no longer directly tied to the production of sound. That is, an entire software mapping block rests between the performer's movements and the sound; a sound may be played and modulated irrespective of a performer's input. "Current technologies can be seen less as recording instruments and more as instruments of control.... The defining factor is the enhanced power to manipulate data that computer-aided technologies can afford" (Sutil 2015, 45). Today, we have the power to blow up an array of speakers with deafening distortion all with the simple push of a button.

Performer-Instrument Relationship Shifts on Digital Musical Instruments

1. Sound-movement relationships may not be perceptible, may have little to no conceived relationship, and/or the relationships may rub against common conceptions of movement and sound.
2. Any established sound-movement relationships may be altered at any time.
3. A performer's physical actions are no longer directly tied to the production of sound. The body cedes physical energy and effort over to technological functions.

1.3 Assumptions

In describing DMIs, I make two basic assumptions. First, I assume a complete instrument based upon the tripartite system described above (Marshall 2008; Miranda and Wanderley 2006). An interface alone is not a DMI. Authors who discuss specific 'instruments' primarily address them with respect to the input controllers or interfaces (Bongers 2007; Marshall 2008). For example, the 169 instruments listed in Piringer (2001) label the type of interface, but leave out the sound synthesis engine or their mapping model. Of course, citing the hardware and physical inputs to the computer can be an easy way to discuss the appropriate DMI. Any specific interface example mentioned herein is treated as a complete instrument (input-mapping-output) unless specifically noted.

Second, I assume digital computing, but acknowledge that DMIs may largely consist of non-digital components (Chapter 7). DMIs represent a burgeoning field of instrument designs and hardware, some of which include microphones, electro-mechanical motors, and even complete acoustic instruments as input devices. The growing number of DMIs comprises an ever-expanding number of general and idiosyncratic parts.

1.4 Organology

The practice of Physical Composition primarily focuses upon alternate controllers, which represents a small class of digital musical instruments. To help define my scope of research, the following section briefly summarizes past research on DMI classifiers.

Digital Musical Instruments belong to a larger category of instruments, Electronic, which itself is a sub-category of yet another family of instruments (see Figure 1-1). Starting with Sachs/Hornbostel's system (1914), which classified acoustic instruments into four families by their acoustics (Kvifte 1989), Sachs' updated system (1940) went as far as to include electronic instruments (electrophones) (Sachs 1940). Kvifte (1989) argues for classification of electronic instruments based upon control actions, but does so through the keyboard synthesizer, largely ignoring other electronic instruments (Kvifte 1989). Bongers (2000) presents a sub-division of electronic instruments; yet, Davies (2001) provides a more complete analysis. Davies divides electrophonic instruments into three sub-categories: ElectroAcoustic (amplified), ElectroMechanical (electrical production; e.g., tone-wheel organ), and Electronic (oscillators; e.g., Theremin, Synthesizer). Jordà (2005) and Patton (2011) further subdivide the Electronic category into Analog and Digital, and Digital is where the computer, and this chapter's investigation, begins.

Many have discussed DMIs in detail, including Pennycook (1985), Paradiso (1997), Mulder (2000), Bongers (2000), Piringer (2001), Davies (2001), Jordà (2005), Birnbaum et al. (2005), Knapp and Cook (2006, 2005), Miranda and Wanderley (2006), Paine (2010), and Patton (2011). Some of the aforementioned subdivide DMIs in intriguing ways; however, most focus on a continuum between traditional and non-traditional interfaces. Like previous authors, I will mainly address 'instruments' in this section with respect to their interface. At times, discussion will include mapping and digital sound synthesis layers (for examples, see Section 1.5.3: On-Body / Off-Body Alternate Controller Case Studies).

Miranda and Wanderley (2006) develop a DMI continuum that spans from the augmented instrument (where sensors are placed onto an existing acoustic instrument) to the non-traditional, alternate controller (see Figure 1-2). Non-traditional controllers have been commonly called "alternate" controllers as far back as 1991 (Wessel 1991), and STEIM articles and authors further

Digital Musical Instruments

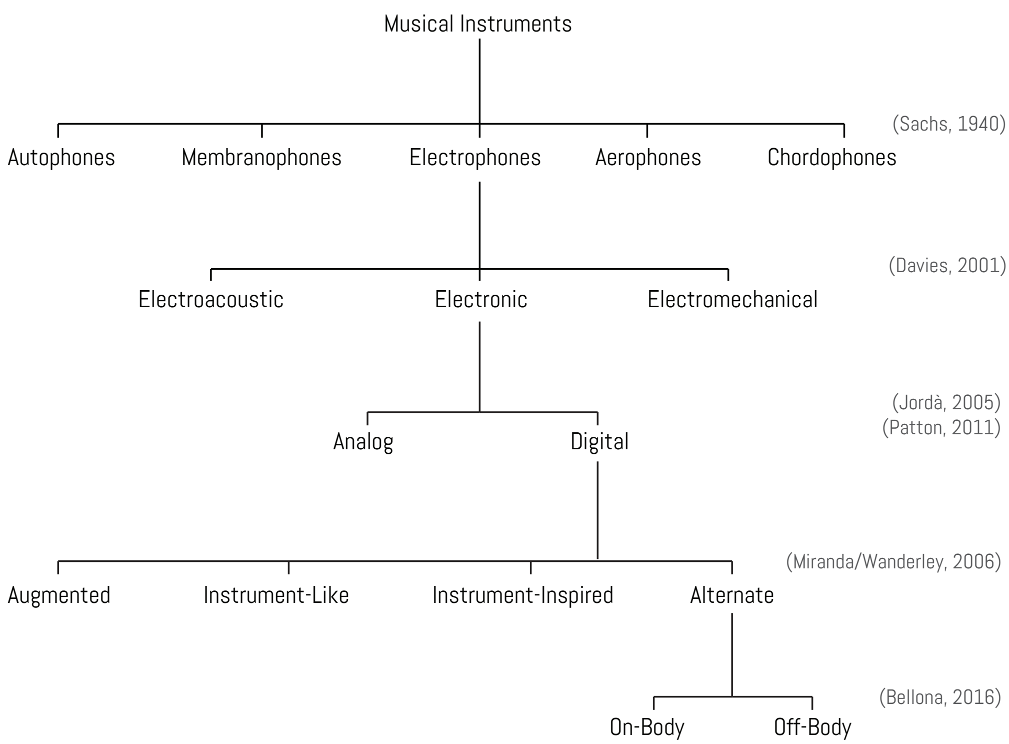


Figure 1-1: Digital musical instrument classification system

used this term throughout the 1990s (Anderton 1994). Miranda and Wanderley acknowledge the widespread use of "alternate," conforming to its use throughout their book on digital musical instruments (Miranda and Wanderley 2006). This dissertation will similarly conform to the accepted term, "alternate."

Figure 1-2: Digital musical instrument continuum

1.5 Alternate Controllers

Alternate controllers contain some of the most radical approaches to instrument design, especially when reviewing the input interface. No firm boundary separates alternate controllers from instrument-like or instrument-inspired models, only that alternate controllers present a different-enough approach (ibid., 20-1). Alternate controllers may provide a novel interaction quality (a result of interface or mapping), or a highly personal approach toward musical expression (Mulder 2000, 318). For a comprehensive, although not exhaustive, list of alternate controller DMIs, see Appendix D.

Like the name suggests, alternate controllers exist as alternatives to traditional musical interface models. Alternate controllers offer an *alternate* path toward musical expression and may be understood through three major creative opportunities. First, alternate controllers offer the potential to create unique sound-movement correspondences and relationships. Since sound producing movements have to be built, performative actions can be creatively explored. "Alternate controllers impose the fewest pre-conceived ideas on performer-instrument interaction" (Brent 2012). Of course, new challenges arise with the creative potential of building new sound-actions. For one, the expansion of choice does not necessarily mean new choices will be implemented, especially given "choice architecture" (Thaler et al. 2009). For example, the ubiquity and stability of the keyboard interface has made laptop performances common, even though some argue that this interface collapses or hides sound-movement relationships

(Ostertag 2002). New technologies also face an implementation challenge—the time spent programming, building, and learning new skills to implement a new DMI often trumps the time spent creating and composing.[4]

Creative Opportunities on Alternate Controller DMIs

1. The potential to create unique sound-movement correspondences and actions
2. The potential to signify (or obfuscate) performer movements, performed sounds, or both
3. The potential to offer individual approaches to musical ideas and performance practices

Because of this potential to develop new sound-movement relationships, alternate controllers also have the potential to elevate attention given to the movements of the performer. Unorthodox technology affords body movement potential—as Waisvisz explains, "The gestural controller... can provide the translation of physical intentions of the composer/performer, ranging form [sic] utmost fragility to outstanding trance, into a set of related timbral trajectories" (Waisvisz et al. 2000, 425). Whether or not composers and instrument designers choose to develop these actions on alternate controllers into rich, physical relationships, movement may play a larger, conceptual role in musical performance.

Third, alternate controllers offer individual approaches to musical ideas and performance practice (Bahn et al. 2001; M. Wanderley 2001). Alternate controllers offer artists a new way of creating music, such that artists may develop their own performance practice exploring their individual ideas.[5] Whether or not the individualized nature of performance practice accounts for idiosyncratic alternate controllers, alternate controllers embody a hope for individualized expression.

[4]Many papers in the New Interfaces for Musical Expression (NIME) conference tackle problems surrounding this creative-time gap, and personal experience composing-performing on DMIs affirms the implementation challenge.

[5]Some notable examples include Michel Waisvisz (The Hands); Laetitia Sonami (Lady's Glove); Atau Tanaka (BioMuse); Nicolas d'Alessandro (HandSketch). STEIM also advances the idiosyncratic model. STEIM pushes technological modularity and recombination, where hardware sensors and software mappings are re-used and re-ordered, in order to "to develop unique instruments for their [artists'] work." STEIM, "What's STEIM," http://steim.org/what-is-steim (accessed May 1, 2016).

1.5.1 Alternate Controller Organology Review

Several authors write about alternate controllers in depth, outlining different input technologies (Marshall 2008; Miranda and Wanderley 2006), trends (Jordà 2005), and classifications (Mulder 2000; Piringer 2001).[6] Patton (2011) overviews DMI typologies and advances his own alternate controller classification schema. This section outlines several of these alternate controller classification approaches, reveals biases and tendencies in each, and lastly, presents a classification system that accounts for notions of performer (Alperson 2008) and instrumentality (Hardjowirogo 2016).

Axel Mulder (2000)

While many authors, like Bongers (1994) and Paradiso (1997), discuss various alternate controllers, one of the first to classify alternate controllers was Axel Mulder (2000). Mulder's alternate controller classification is shown below (Figure 1-3).

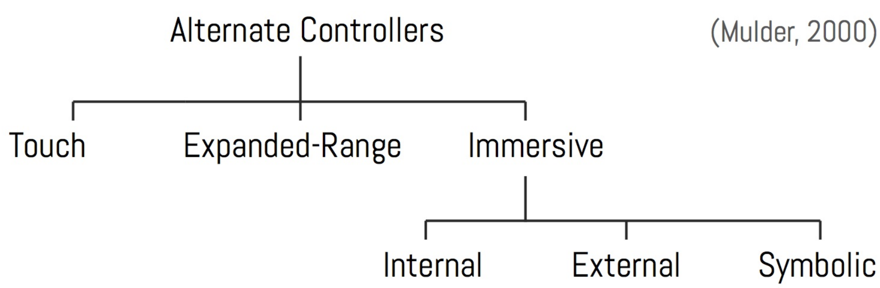


Figure 1-3: Alternate controller categories, Mulder (2000)

Mulder's 1998 dissertation examines alternate controller sub-types with a focus upon gesture, chiefly hand gestures (Mulder 1998). Mulder's previous research includes building a Data Glove instrument (Mulder 1994) and cataloging HCI Hand Gestures (Mulder 1996). It should be no surprise then, that Mulder centers his categories and values around the capability of the hand. For example, Mulder reasons that Buchla's Lightning is not an immersive controller, since "due to the fact that the hands need to hold the infrared transmitting unit hand shape variations are restricted" (Mulder 2000, 321). The only non-technical comment on the Radio Baton further

[6] Given the problematic nature of Mulder's alternate controller categories outlined below, this paper will not address Jörg Piringer (2001), who discusses alternate controllers through Mulder's categories.

underscores Mulder's values, "hand shape could not be used for performance control" (ibid., 321).

Instead of an even taxonomy, Mulder describes these categories in a sort of hierarchical order, with "Immersive" as the capstone. For Mulder, "hand shape variations," described as immersive controllers, are the "best suitable for adaptation to the specific gestural capabilities and needs of a performer" (ibid., 324). Mulder assumes that a performer's needs are best suited by the use of her hands, even though not all performative actions are finger/hand specific, let alone require the use of the hands at all.[7]

Lastly, Mulder values alternate DMIs based upon their "gestural range."[8] To Mulder, expanded range controllers "have a limited range of effective gestures" (ibid., 320). His statement sidesteps defining what constitutes "effective," especially considering that Mulder labels Michel Waisvisz's The Hands an expanded-range controller. What are "effective gestures" and how do they limit Waisvisz musically?

Mulder's hierarchical valuation of alternate controllers raises additional questions. Can one hierarchically order the instrumental interface? Should we order musical instruments on the importance of hands in the actuation of music? By prioritizing the hand on the basis of "few or no restrictions to movement" (ibid., 324), Mulder's categories seem to devalue touch. Indeed, "touch" is the lowest order of Mulder's categories. And in the evolution of alternate controllers, many notable composers and instruments still implement touch and fine-motor control into their systems.[9]

Sergi Jordà (2005)

Sergi Jordà (2005) discusses various taxonomies for alternate controllers as an overview of his own work, and he describes most of his classifications via Joseph Paradiso (1997). Yet, two main issues persist. First, Jordà cedes he is not concerned with categories.

[7]A popular music example is Rick Allen, the drummer for Def Leppard, who used digital technology to assist his playing after he lost his arm in an automobile accident.

[8]Mulder defines gesture as a "use of the hands for communication purposes without physical manipulation of an object" (Mulder 2000, 317).

[9]Some notable examples include Michel Waisvisz's The Hands, Laetitia Sonami's Lady's Glove, Sensorband's Soundnet, Walter Fabeck's Chromasone, Onyx Ashanti's Beatjazz, Peter Bussigel's n-dial, and Christophe d'Alessandro's Cantor Digitalis.

> The examples that follow do not represent any technologically or musically biased categories. They are included it [sic] here because many of the following devices are (a) cheaper than musical controllers, (b) widely available and (c) not necessarily less functional (Jordà 2005, 41).

Second, Jordà is vague within his descriptions; for example, when he describes a video input system as relational to a microphone. “They are not microphones but they relate to the voice, mouth or tongue” (ibid., 41). Jordà assumes, broadly, that microphones relate only to the voice, and that video only relates to the physical attributes of the voice. Jordà’s classification of Paradiso is shown below (Figure 1-4) (ibid., 36).

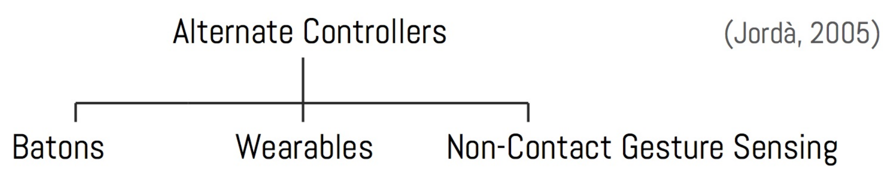


Figure 1-4: Alternate controller categories, Jordà (2005) via Paradiso (1997)

Paradiso (1997) is primarily concerned with describing musical interface history and interface research through a myriad of interface examples. These examples include hyperinstruments, instrument-like, instrument-inspired, and alternate controller interfaces. As such, this dissertation will simply address these non-traditional, alternate controller examples within the Appendix (Appendix D).

Kevin Patton (2011)

Kevin Patton (2011) describes DMIs differently, choosing instead to bisect DMIs into Studio-Performance classifiers before offering “interface ontologies” (Tactile, Audio Control, Gestural, Biometric) and “mapping ontologies” (Analytic, Kinetic, Modular, Interactive) (ibid.). Patton offers a thorough overview of data-stream typologies and previous classification systems. However, Patton’s own classification system is loosely defined. For example, Patton only defines Biometric through Bongers (2000). “Burt [sic] Bongers organizes different sensors according to the kind of physical intervention that is required to create the data: Muscle Action (Isometric/Isotonic), Blowing, Voice, and Bio-electricity (different kinds of biometric data)

[Bongers, 2000, p. 10]" (Patton 2011, 18). Patton does not explain how if biometric refers only to "bio-electricity," how his Tactile, Audio Control, and Gestural categories correspond (or not) to Bongers' Muscle Action, Blowing, and Voice categories. Patton does not further refine his term "biometric" in any other way.

Neither does Patton discuss why specific "interface ontologies" are left out from his Studio classifier (ibid., 53). For example, Patton excludes Gestural (e.g., Wacom) from the Studio classifier altogether. Patton earlier acknowledges joysticks as a potential Gestural interface (ibid., 21), and joysticks along with other Gestural controllers can be found on instruments deployed in the composer's studio (e.g., Pacom, VCS-3, UPIC).

1.5.2 On-Body / Off-Body Alternate Controllers

Following Bongers who supports the notion of "performer-system" in terms of "interaction within the electronic arts" (Bongers 2000, 46), this next section outlines an interaction-based DMI classification system. By emphasizing the use of two labels, On-Body and Off-Body, the classification attempts to balance the body of the human performer alongside the body of her DMI. On-Body / Off-Body seeks to account for past and current controllers, to foster discussions on DMI development (input, mapping, sound synthesis), and strives to equitably consider both sides of the performer-instrument relationship. The On-Body / Off-Body alternate controller classification is shown in Figure 1-5.

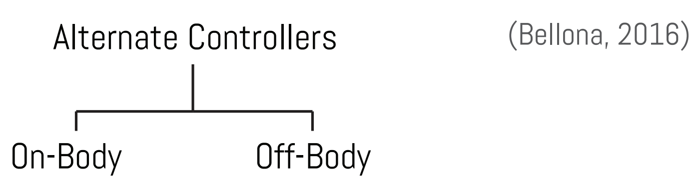


Figure 1-5: Alternate controller categories, Bellona (2016)

As mentioned previously, technology divorces the transfer of physical energy from the production of sound. A disconnect between the performing human body and the resulting sound does not necessarily mean that the body is severed from digital music altogether. As Alva Noë suggests, "the digital is just a different way of making the movement happen" (Noë 2012, 60).

The most prevalent interactions with alternate controllers still involve the human performer.[10] On-Body / Off-Body categories point toward an interactive approach, encompassing ergonomic and performer-centered considerations.

On-Body

One may think generally of On-Body alternate controllers as wearables. Technological objects are worn on the body—biosignal sensors (e.g., EEG headsets), datagloves, sensing armbands—On-Body alternate controllers move where the body moves in space. Technologies may limit movement range (e.g., Emotiv headset, EKG tab electrodes), or enable larger movements (e.g., Myo armband, BioMuse), but regardless of how movement is employed (technologically or compositionally), On-Body alternate controllers are attached to the body.

While On-Body alternate controllers may contain tactile/non-tactile interactions, the performer-instrument relationship is tethered to fluctuations of the body, regardless of the visibility of movement. For example, John Mantegna's *Wetware Fantasy #1* (2013) for Emotiv headset and Kyma, relies upon a seated performer focuses upon his/her own brain activity in order to sound the musical work.[11]

On-Body alternate controllers typically utilize sensors that focus on internal body control (e.g., heart rate, muscular contractions, brain waves), proprioception, and spatial information (e.g., acceleration, velocity, gyroscope). That is not to say that all On-Body alternate controllers utilize these sensor types. Michael Lyons, Michael Haehnel, and Nobuji Tetsutani's Mouthsizer (2003) is a headset video camera that sends video of the mouth and face, where the mouth, via video, controls synthesis parameters (Lyons et al. 2003). By wearing a video camera (keep-

[10]The value of the human here is not meant to denigrate robotic or automated systems. It is the nature of computing technology to utilize computing processes and automated system(s). Automated systems are being deployed for musical performance, as well as robotic devices as musical performers. It is out of the scope of this dissertation to unpack aspects of robotic performance as well as any discourse surrounding computation as intent. There are many valuable and stimulating musical systems, but due to the lack of time and space, these just cannot be discussed. For additional reading on automated systems please see Jonathan McCormack, Alice Eldridge, Alan Dorin, and Peter McIlwain, "Generative Algorithms for Making Music: Emergence, Evolution, and Ecosystems," in *The Oxford Handbook of Computer Music*, ed. Roger T. Dean (New York, N.Y: Oxford University Press, 2009), 354–79. For more on robotic musical performance please see Jorge Solis and Kia Ng, eds. *Musical Robots and Interactive Multimodal Systems*, Springer Tracts in Advanced Robotics, v. 74 (Berlin: Springer-Verlag, 2011).

[11]Symbolic Sound, http://kiss2013.symbolicsound.com/program/ (accessed January 30, 2017).

ing the camera-to-mouth video relatively constant) that emphasizes the internal control of the mouth and tongue muscles, the On-Body label underscores the performer's relationship to their technologized body.[12]

Off-Body

Like the name suggests, Off-Body alternate controllers represent more of an external interface with which the performer interacts. In fact, most traditional instruments may be thought of in this way—an engagement with an external object. Some common external interfaces include joysticks and pads (various array of buttons/faders), drawing and mobile tablets, video game controllers (e.g., Dance Dance Revolution, Gametrak), IR proximity sensors, and capacitance sensing. These technologies and interfaces usually require some type of overt activity, whereby the data sent from the interface typically describes an interaction between a performer's body and the external sensor. Of course, video cameras and other sensing technologies may describe the moving body (e.g., David Rokeby's Very Nervous System, Jon Bellona's simpleKinect software) or the body interacting with an object captured by video (e.g., Jaime Oliver and Matthew Jenkin's Silent Drum). Because sensing technologies do not require a human performer to touch a physical object, Off-Body alternate controllers may include both interactive objects (tactile) and interactive technologies (non-tactile). (For specific case studies, see Section 1.5.3).

Additional Considerations

As alternate controllers, On-Body / Off-Body instrument categories follow the tripartite definition of a DMI (see Section 1.1), and consider Magnusson's contextual format of a digital instrument (Magnusson 2009). Through Waisvisz, Magnusson argues that tinkering with software and hardware may create a "new (or altered) instrument" (ibid., 169, fn 1). In this way, Lukas Steiner's Elements (2011),[13] employing a Wiimote attached to the waist, feeding an IR sensor, and using Kyma for sound synthesis, should be treated differently than Wiimotes used as part

[12] I highly recommend trying to play a silent Mouthsizer. Open your mouth wide, then slowly form mouth positions to sound out vowels (a, e, i, o, u). Imagine combining various positions to craft a performance. Is the experience more internal or external? On-Body or Off-Body?

[13] Performance video available online. Symbolic Sound, http://kiss2011.symbolicsound.com/videos-photos/ (accessed January 30, 2017).

of a piece for L2Ork (Linux Laptop Orchestra). Both contexts share input controllers, but the instrumental controls are completely different. A Wiimote can be treated differently as part of different DMIs; after all, a Wiimote is just an input controller, and constitutes but one part of a DMI.

Comparably, IR proximity sensors can be employed differently across instruments (e.g., Chikashi Miyama's Seven Eyes, Butch Rovan's GLOBE, and Zbigniew Karkowski's IR Cage). Similar to how Norman (2002) discusses the affordances of everyday objects in relationship to human interaction, the affordances of sensor inputs shift when combined with the mapping and sound synthesis elements in a DMI. When a technology alters its function, the performer-computer context may offer up strikingly different possibilities for musical performance.

The creative potential of alternate controllers resides in the interactions between performer and instrument. Understanding the alternate controller DMI (i.e., input—mapping—output) and its relationships to the performer's body can open up creative play and possibility. Body relationships to digital technology reveal affordances that the composer-performer may treat musically. It is through an embodied relationship to digital technology that we may better navigate our own personal relationships toward DMI performance practice.

1.5.3 On-Body / Off-Body Alternate Controller Case Studies

To further delineate the categorical spectrum, this section details several examples of On-Body / Off-Body alternate controllers. Each example will assess musical and performance criteria with respect to On-Body / Off-Body labels. Examination of a border case will emphasize the classifiers as fluid continuum.

On-Body Case Study: The Hands

One of the earliest examples of an On-Body alternate controller is Michel Waisvisz's The Hands. Created in 1984 at STEIM, The Hands combine discrete and continuous sensors onto two controllers attached to the performer's hands.[14] The interface is worn on the body.[15] The Hands enables spatial freedom of the arms and hands; Waisvisz actuates touch controls regardless of where his hands are in space. In addition, by locking the alternate controller onto his hands, Waisvisz is able to utilize an ultrasonic sensor as a form of "bowing," where "scratch mode" is coupled with sustain (Bellona 2017). Waisvisz's body becomes part of the interface—that is, the physical attachment of the controllers makes them central to the performer's body in the visual domain—the interface is bound to the performer. Waisvisz is simultaneously a puppet and puppeteer, where "one seems to act immediately in sound and not in 'terms of sound' and not in terms of 'control.' Composition/performance melt into a single state of emerging - timbral - expression" (Waisvisz 1999, 425).

Video 1-1: Example of The Hands, version 2, by Michel Waisvisz. Performance video of Michel Waisvisz and Shelley Hirsch from De Zoetgevooisde Bliksem festival (1993).

On-Body Case Study: Xth Sense™

A more contemporary example of an On-Body alternate controller is Marco Donnarumma's Xth Sense™, where two sub-sonic microphones worn on the forearms transmit muscle sounds (Donnarumma 2011). These sounds are normalized and filtered in Xth Sense™ software, being treated as both audio and control signals. While microphone amplification would typically be classified under an electroacoustic label, the use of body sound as control signal sets this On-Body alternate controller apart. In fact, the latest version of Xth Sense™, XTH, includes added biosensors that transmit additional control signals (Donnarumma 2016b).

Video 1-2: *Ominous* (2013) on Xth Sense™ by Marco Donnarumma (Donnarumma 2014)

[14] There are three hardware versions of The Hands, and the author considers all in the case study (Torre et al. 2016).

[15] Waisvisz did remove The Hands at the very end of performances in the mid 1980s as a calculated musical coda (Bellona 2017).

Off-Body Case Study: *n*dial

Peter Bussigel's *n*dial is an Off-Body alternate controller equipped with several buttons, switches, dials, and an internal gyroscope. The *n*dial "combines automated sampling and sequencing with manual controls," where the *n*dial is a physical object the performer interacts with (Bussigel 2016a) (see Video 1-3). The *n*dial interface controls *Onism*, a custom-made software written by Bussigel (Bussigel 2016b). The software controls loop sequences, shifting samples, playback speed and volume, among other parameters.

Video 1-3: Demonstration video of *n*dial, by Peter Bussigel (Bussigel 2016a)

Off-Body Case Study: HandSketch

Pen-on-surface is an off-body, tactile interaction and one notable interface, the Wacom tablet, has been found in many performance contexts and instrument designs, including the author's.[16] Nicolas d'Alessandro's HandSketch[17] employs the Wacom tablet through an ergonomic approach, taking advantage of the rotation of the pen-holding arm in the mapping schema and adding button controls on the tablet for the left hand (d'Alessandro and Dutoit 2007). HandSketch controls d'Alessandro's original voice synthesis models, and in writing and performing, d'Alessandro takes a tonal approach. The left-hand FSRs control discrete pitches relative to the pen, enabling an ornamental performance practice, not dissimilar from Baroque or Classical traditions. An overlaid transparency displaying pitch helps direct the performer, and in *Circle of Doubts* (2013), d'Alessandro adds a multi-track loop function to create a contrapuntal harmony (see Video 1-4). Recently, d'Alessandro has attached an iPhone to the tablet for additional

[16] For an additional list of Wacom specific DMIs, see Appendix D. For other examples, Zbyszynski et al. recount ten years of using the Wacom tablet for musical applications. Michael Zbyszynski, Matthew Wright, Ali Momeni, and Daniel Cullen. "Ten Years of Tablet Musical Interfaces at CNMAT," In Proceedings of the International Conference on New Interfaces for Musical Expression (New York: NIME, 2007), 100–105.

[17] Nicolas d'Alessandro is not to be confused with Christophe d'Alessandro, who also works with Wacom tablets and collaborated with Nicolas d'Alessandro in 2006 on CALM synthesis, which is now part of Christophe's Cantor Digitalis instrument.

left-hand control (d'Alessandro 2016).

Video 1-4: Circle of Doubts (2013) on HandSketch, by Nicolas d'Alessandro (d'Alessandro 2013)

Off-Body Case Study: Seven Eyes

Off-Body alternate controllers may also utilize non-tactility. Chikashi Miyama's *Seven Eyes* instrument has seven IR proximity sensors, which afford an off-body, non-tactile performance interaction. Miyama's performance of *Angry Sparrow* (2008) for Seven Eyes demonstrates how non-tactile control activates performer-instrument interactions (see Video 1-5). By developing arm and hand movements within the limited space of these seven sensors, Miyama manifests unique sound-movement relationships.

Video 1-5: Angry Sparrow (2008) on Seven Eyes, by Chikashi Miyama (Miyama 2008a)

Off-Body Case Study: Silent Drum

An interface may include technologies that are both tactile and non-tactile, as with Jaime Oliver and Matthew Jenkin's *Silent Drum* (Oliver and Jenkins 2008). In *Silent Construction 1* (2009), the performer tactilely presses against a flexible membrane attached to a drumhead; however, the input to the computer is a video camera that captures a vertical plane of the membrane.

Video 1-6: Silent Construction 1 (2009) on the Silent Drum, by Jaime Oliver (Oliver 2009)

On-Body / Off-Body Border Case Study: Chromasone

On-Body / Off-Body may be thought of more as a flexible continuum than as discrete containers. For example, Walter Fabeck's Chromasone incorporates Datagloves worn on the hands and an external 3D tilting interface. The instrument straddles the two classifiers. Yet, it is these two labels (On-Body / Off-Body) that stress Fabeck's relationship with his instrument. First, on-body hand control is essential. "I have taken the ESSENCE of piano performance and articulation, and placed it in a new context, to create a new instrument. The essence is the movement of ten fingers at a certain position in space. This spatial location of the hands is crucial" (Fabeck 2000). Second, Fabeck favors whole body interaction. "It seems to me axiomatic that neuro-muscular control devices must approximate to the range of movement appropriate to our physiology; in other words it seems ludicrous to try to articulate a dynamic range of c.90dB with fader or mouse movement of a few centimetres, especially in a live performance" (ibid.). Chromasone exists as both an On-Body and Off-Body alternate controller DMI, and the labels appropriately underscore the two main design and performance features of the instrument.

Video 1-7: *Cage* (1994) by Walter Fabeck on the Chromasone. Performance at STEIM, Amsterdam, April, 1994.

1.5.4 Performer-Instrument Controls

The technology of musical instruments and their performers constitute a type of expressive symbiosis (Alperson 2008). On-Body / Off-Body categorization of alternate controllers acknowledge the complex performer-instrument relationships vis-à-vis the technological negotiation of the performer's body. Irrespective of how we account for DMIs, digital technology has increased the human body's potential in music. Composers have the capability to transform corporeal movement into digital electronic sound, and may continuously mold these sounds through the dynamic shape of body activity. While not every technological change may be viewed as beneficial to the relationship, DMIs do offer the musical performer new opportunity. Body signals may become control signals. Muscle sounds, brain waves, non-tactile movements may serve as elements of control. The changing role of the performer through digital technology does not diminish the presence of the performer's body. Instead, digital technology amplifies the physical body as a controller of musical sound.

Chapter 2

Paradigms of Control

> Musical art is an experience of *making*, of bringing sound forward to the senses through the mobility of our bodies in action.
>
> Nicholas Brown (N. Brown 2006, 41)

As discussed in the previous chapter, a digital musical instrument (DMI) organology that considers the body in relation to digital technologies reorients the discussion of how humans shape musical practices. The classifiers for alternate controllers, On-Body and Off-Body, focus on what Nicholas Brown would describe as "enabling the presentation of new agendas for composition that (re)connect our ears to images of sounding movement" (ibid., 45), and help elucidate music composition as embodied action on DMIs. In this next chapter, *paradigms of control*, DMI composition as embodied action is explored in terms of three spatial arenas that tie the concepts of the body to musical potential.

Paradigms of Control on Alternate Controller Digital Musical Instruments

- Parametric Kinesphere
- Situational Kinesphere
- Hidden/Digital Body (of Data)

Each one of these paradigms of control—the parametric kinesphere; the situational kinesphere; and the hidden, digital body—describe different views of the performer's control (and what controls the performer). First, there is the *parametric kinesphere*, a space around the body that immediately describes the instrumental interface in accordance with the performer and their actionable movement. The parametric kinesphere outlines performed actions and their relation to musical controls.

Next, there is the *situational kinesphere*, a space describing the external factors that may influence the musical agents, placing an affordance on the musical context. Often these factors are felt but not heard. The situational kinesphere imposes order on moving bodies and sound from the outside.

Third, moving within the parametric kinesphere, there is the hidden spatial structure of software that supports the physical interface and determines how sound is produced and modulated. This *hidden* layer of software acts as a *digital body* on which all DMIs depend. The filters, decision trees, and data coded structures in the DMI help form the body of response elicited by the performer and aid the quality of musical choice.

Movement Types

Within the three paradigms of control reside different movement types—instrument, body, sound, situation—and each movement type can inform any one of the paradigms of control (Figure 2-1). First, *instrumental movements* are movements that intersect with performer and instrument. These movements may embody internal body actions (e.g., tightening of muscles to produce sounds captured on Marco Donnarumma's Xth Sense) or constitute entire body movements (e.g., shaking an 11x11 meter wire grid above the floor in Sensorband's Soundnet). Instrumental movements may include mute operations like control state changes; the movements constitute a dialogue between the body and the instrumental interface, which can help composer and performer negotiate software and hardware choices. For example, the sound controlled by moving a 'fader' rendered as a wire stretched across the stage may connote differently than a fader on a mixer. Not all body movements control sound parameters, and therefore instrumental movements reside within a body movement space.

Second, *body movement* informs control. Understanding how the body moves in space is critically important to the successful translation of that movement into musical sound. For example, the ergonomics of the wrist and arm led d'Alessandro and Dutoit (2007) to adapt their software to fit the body, and they developed a transparent overlay for the Wacom tablet to

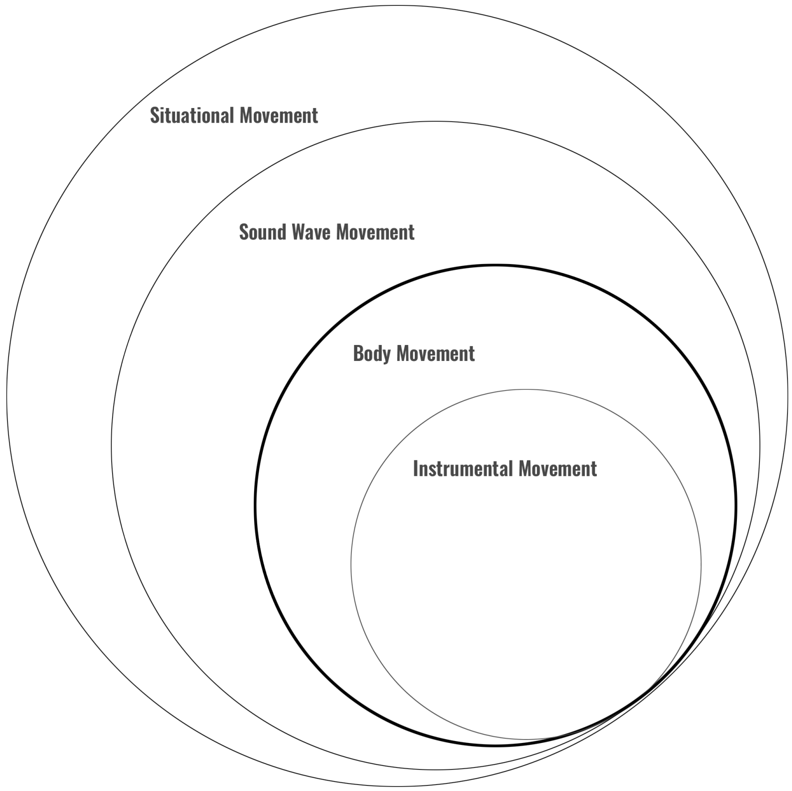


Figure 2-1: Movement types within musical performance

support this movement. Understanding body limits and body awareness (e.g., proprioception) may help performer, composer, and instrument builder negotiate the digital music terrain (even if the agents are one and the same person). Body movements can include instrumental and non-instrumental activity.

Third, *sound wave movement* informs control. The production of sound and how sound changes over time can influence choices about instrumental inputs and their respective sonic outputs. Bongers (2000) describes this type of sonic feedback as an "interaction modality" (45). The movement of sound in space impacts how we listen; the phase, frequency, timbre, amplitude, etc., of sound(s) and their interaction in acoustic space affects the perception of sound (Truax 2001). Within a musical performance context, where multiple factors may be altered simultaneously, the movement of sound can communicate ideas about how we might control sound.

Fourth, the *movement of situation* informs control. The audience and culture may all lobby actions and normative behaviors from the musical agents involved (Small 1998). For example, how a crowd responds during a work can impact the movements of the performer, which as a result, impacts the sound. Hardjowirogo (2016) includes the situation within her criteria for instrumentality, referencing how "immaterial" factors press upon the agents of performance (21). Broadly speaking, these movement types—instrument, body, sound, and situation—can inform the paradigms of control.

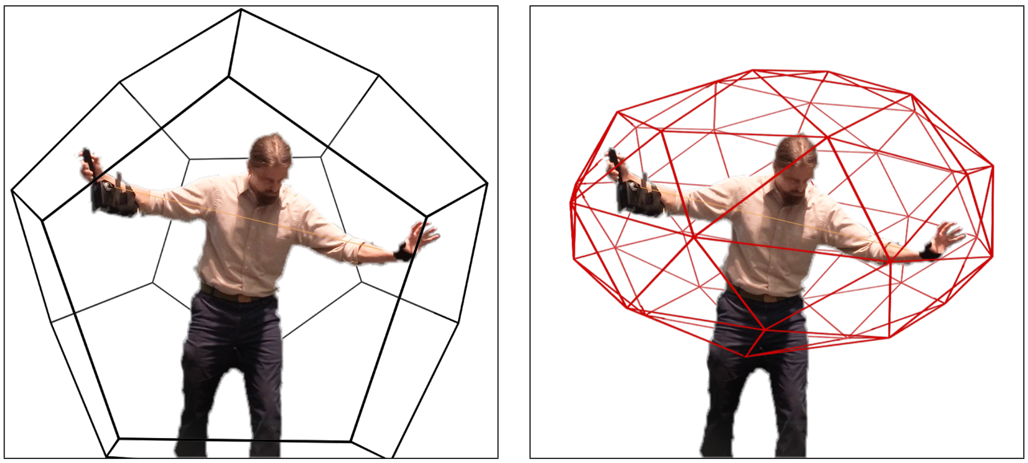
For example, when I perform *HMW-mult3* (2017) on my DMI, Distance-X (Video 6-13), I am constantly navigating the musical territory. My *body movements* alter my body's kinesphere, and accounting for my body in its relation to this instrument, I enact *instrumental movements*, whereby I implement sound-creating actions, such as triggering an audio sample, and sound-modulating actions, such as widening a filter.

Extending outward from my body, but included in my somatic and aural experience as a performer, the physical sound vibrations, or *sound wave movements*, inform how I move. The sounds and their spatialization interact with my body, my ears, and the acoustic properties of the space, further impacted by the placement of the speakers and the floor monitor, the type of speakers, the mixing engineer, and any inserts placed along the signal path, all of which color my perception. Lastly, *situational movements*, those immaterial and fluctuating factors of the venue and my listeners, inform my performance and how I might react (or take mental notes in order to make changes later). A concert setting full of seated participants may elicit certain behaviors from my performance than a rowdy crowd in a dive-bar. Just as a resounding boo by a concert-goer may provoke a response, however slight, so too can my performance realign the situation.

2.1 Parametric Kinesphere

Parametric kinesphere is the spatial area of and around the body that controls sonic parameters. The concept of kinesphere is borrowed from movement theory and refers to "an imaginary space we are able to outline with our feet and our hands," the spatial area that the body moves within (Sutil 2015, 20). Rudolf Laban (1966) first presented the kinesphere as a "sphere around the body," the space that extends around the *potential* of body movement (10). Our kinesphere, or "periphery," shifts with the locational planes of movement, such that the sphere dynamically shifts with the moving body (Laban 1966, 10).

Parametric kinesphere ties the body of digital instrument and body of performer together spatially into a performance ecology. The body defines one spatial boundary and the instrument controls further limit the spatial area of the body linked to sound controls. An example of body and parametric kinespheres is shown in Figure 2-2.



(a) Body Kinesphere (b) Parametric Kinesphere

Figure 2-2: Kinesphere for Distance-X. Parametric Kinesphere moves with the space of the hands and the position of the controller, as the distance and angle between hands effects sonic parameters.

Initially, one may not understand how the controls and resulting sounds of a new DMI work. For example, Michel Waisvisz's The Hands, presented in 1984, did not look nor sound like a conventional synthesizer. However, we understand and appreciate physical effort through our own somatic experience. The Hands manifests the performer's input into its musical system by emphasizing the performer's parametric kinesphere.

With The Hands, Waisvisz's hands and arms define his parametric kinesphere. The physical movements of the arms directly control amplitude (distance values reported by an ultrasonic sonar sensor) (Torre et al. 2016). Thus, Waisvisz's parametric kinesphere couples sonic and visual effect, marrying physical to musical action. Figure 2-3 depicts the physical range of Waisvisz's instrument within his parametric kinesphere.

The Hands also offers something novel in its digital design: the idea that controls on the instrument can alter how the instrument responds, changing the musical relationship between the performer and instrument midway through a piece. Waisvisz designed the instrument to

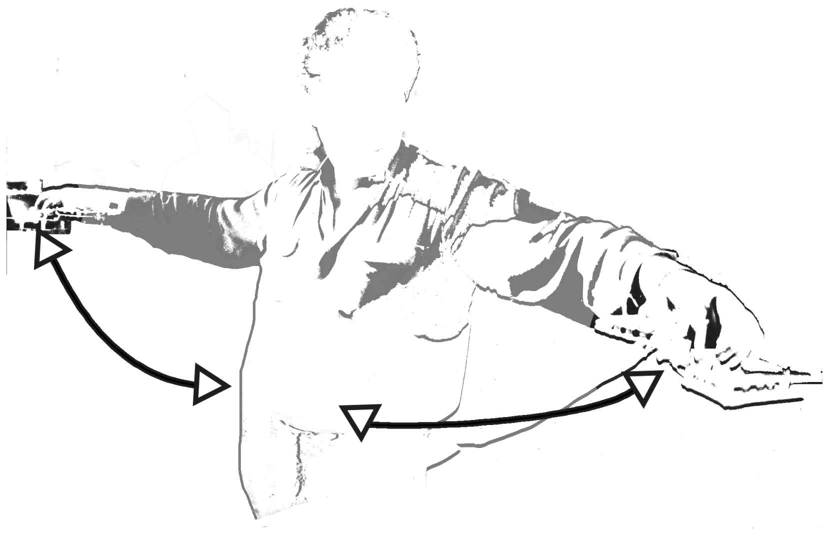


Figure 2-3: Range of Waisvisz's Parametric Kinesphere on The Hands. Original image ©STEIM. Used with permission.

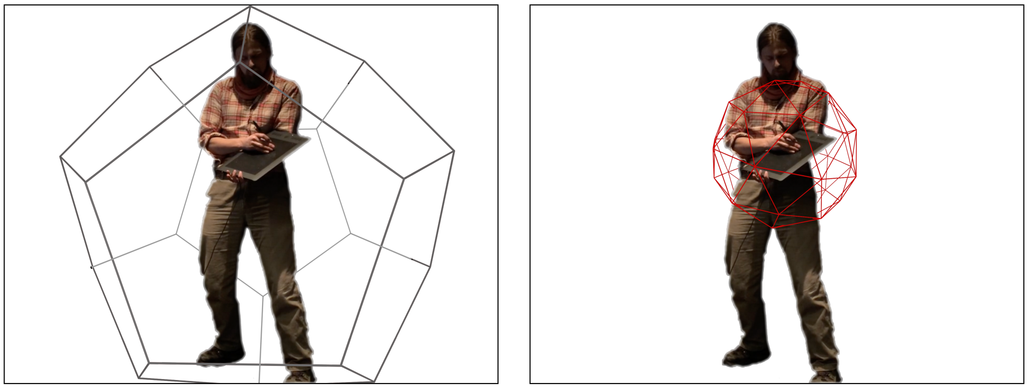
toggle "scratch" mode on and off, which altered "the algorithm for the translation of sensor data into music control data" (Waisvisz 1999, 425). By activating "scratch" mode, Waisvisz changes the ultrasonic sensor mapping, which allows his arm movements to additionally control Note On messages. The mode offers new possibilities in sound: "Holding down the button and moving the hands produces a scratching or ripping effect. If the sustain button is engaged at the same time, the effect is more like a bowed string which constantly changes in volume" (Lehrman 1986, 22). "Scratch" mode links arm movements to new sonic actions (bowing, scratching) that extend existing sound-movement relationships of amplitude. By adding the translation of physical arm movements into note events at the flip of a switch, Waisvisz expands the effective physical movements that manifest musical relationships, and his parametric kinesphere now contains these new controls as a result.

Parametric kinesphere attempts to account for the functioning of the body in sound mapping, what Wilson-Bokowiec and Bokowiec would describe as "the experience of the performer and the nature of the relationship that is forged between performer and technology through kinaesonic actions" (Wilson-Bokowiec et al. 2006, 47-48). Kinaesonics here describe "the physicalization of sound or the mapping of sound to bodily movements" (ibid., 47). Culturally, we have developed an understanding of movement-sound relationships on specific acoustic instruments in the physical world. We understand that a performer moves in space but not all of the performer's movements control or activate inputs. The development of movement-sound relationships on DMIs and virtual systems may still be in its historical infancy, but leveraging the embodied knowledge of body movement–its strengths and its limits–can empower the composer and performer in the digital instrument environment. For example, we know how to push, grab, yank, touch, caress, squeeze, kick, stomp, fall, catch, among hundreds of other physical actions. The creation of a DMI leverages our actions or constrains them, and this type of instrumental expansion and contraction is represented spatially with the parametric kinesphere.

While I did not develop parametric kinesphere in order to examine musical devices, the framework does offer a way to compare DMI's spatial parameters. Birnbaum et al. (2005) discuss a dimension space for examining musical devices based upon seven key factors related to performance. Although one factor assesses the distribution of "total physical area," the scale does not magnify the kinesphere of the "local" performer (ibid., 194). Magnusson's (2010) epistemic dimension space moves the other way, analyzing system design in relation to the conceptual and theoretical aspects of the instrument (Magnusson 2010a). A parametric kinesphere, however, provides a spatial understanding of the perceptual overlap between movement and sound. Figures 2-2, 2-4, 2-5, 2-6, and 2-7 depict several DMI interfaces and their respective parametric kinespheres.[1]

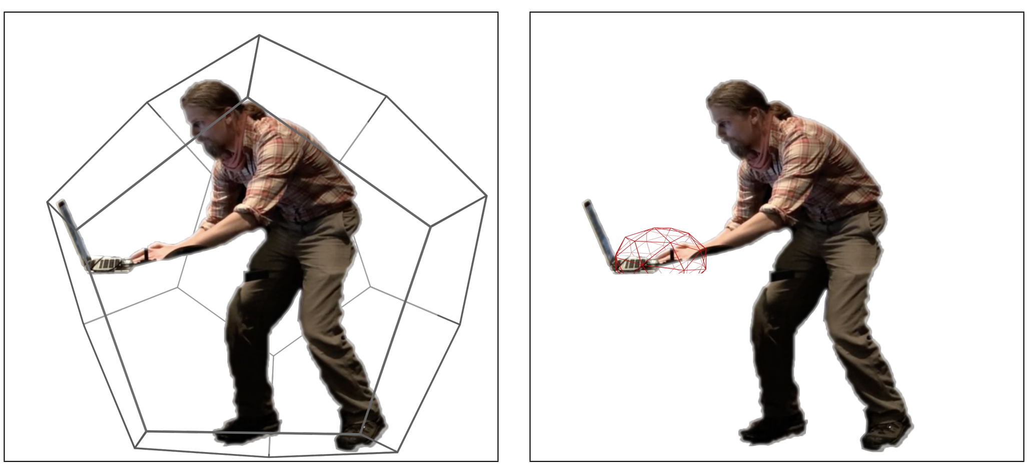
With digital technology, the proxemic space of musical kinespheres may now include the virtual, the telematic, and the distant. One's parametric kinesphere in a virtual system may be thought of as contained within both physical and virtual space. For example, Atau Tanaka's *Global String* connects two physical objects through virtual nodes of video and data (Tanaka and Bongers 2002). A musical action in one location (and on one side of the screen) causes musical activity in the other location. The action fed through a physical string and through a video screen, which depicts the other end of the string, underscores how the engagement and the connectivity take place in both physical and virtual spaces. The piece reveals how the musician can simultaneously be inside and outside their own body kinesphere during a performance.

[1]As kinespheres are dependent upon movement potential and time, any such parametric kinesphere shown represents a singular slice of time dependent upon both the body and its software controls.



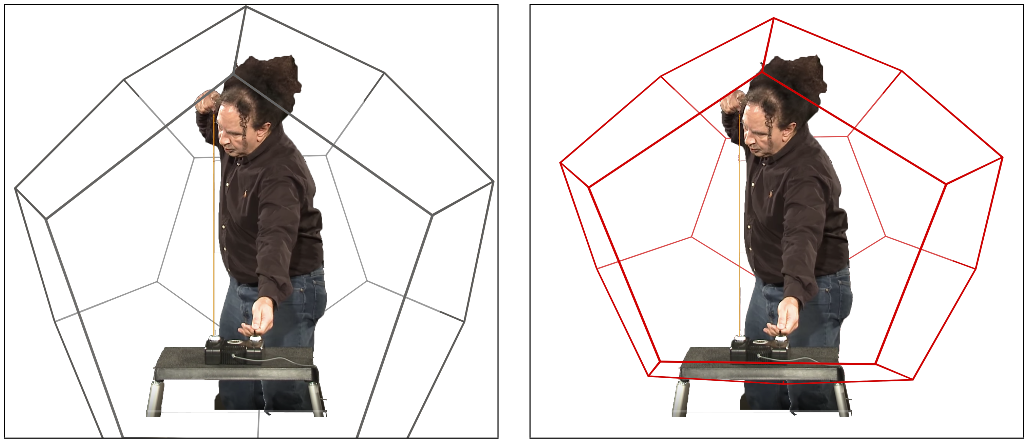
(a) Body Kinesphere (b) Parametric Kinesphere

Figure 2-4: Kinesphere for Wacom tablet. Parametric Kinesphere moves with the hands, as the tablet is held and angle of arms can effect Pen Tilt, one of the sonic parameters.



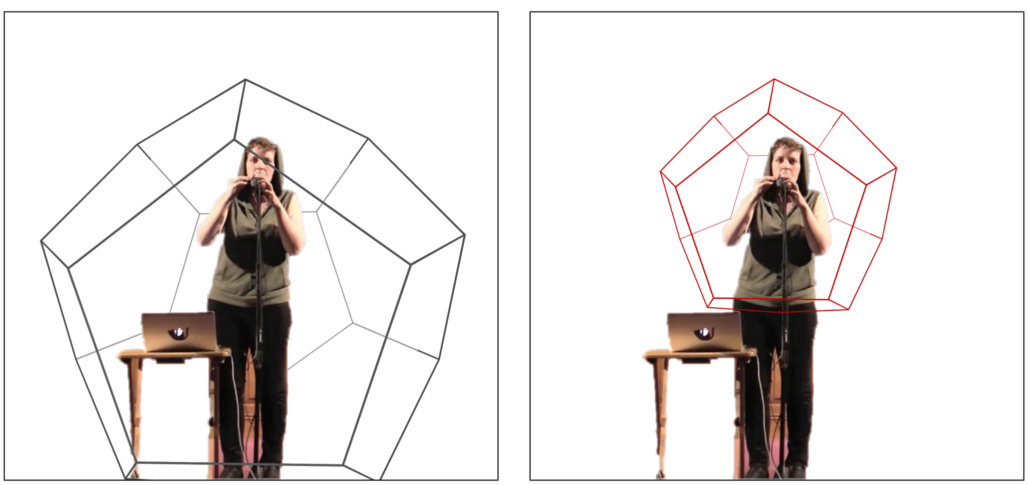
(a) Body Kinesphere (b) Parametric Kinesphere

Figure 2-5: Kinesphere for laptop. Parametric Kinesphere cannot move from table, as the laptop is fixed, and the screen mostly hides views of its parametric space.



(a) Body Kinesphere (b) Parametric Kinesphere

Figure 2-6: Kinesphere for Jeffrey Stolet's *Lariat Rituals* (2012). Parametric Kinesphere moves with body but does not move from table, as the Gametrak rests atop the table throughout the piece. Video still © 2012 Jeffrey Stolet. Used with permission.



(a) Body Kinesphere (b) Parametric Kinesphere

Figure 2-7: Kinesphere for Kristina Warren's *Abacus* (2016). Parametric Kinesphere does not include the computer; the performer combines voice and a custom built microphone, which contains all of the necessary performance electronics. Video still © 2016 Kristina Warren. Used with permission.

2.2 Situational Kinesphere

Before music is sounded within a space, there is the situation that encompasses the music. There is a musical context for the composition: the venue, the dress, the lighting, the musical agents, the technologies, in addition to other elements. A sound is shaped by the environment in which it sounds, as are the choices and actions of the music.[2] Small (1998) discusses the varying degree to which the orchestral concert setting influences behaviors of the audience and performers. The situation is a paradigm of control. The situational space, or *situational kinesphere*, describes these broader musical contexts that inform musical choice. The situational kinesphere can involve cultural, geographic, spatial, historical, or temporal boundaries.

Each situation may contain diverging music traditions, but the social acts of music posit their own norms that influence the choices around movement and sound. Salazar-Sutil describes these controls as "'social controllers,' or socially normative mechanisms that govern the way we move, that determine the places where we move to and from, that program the motives (the desires, appetites, intentions) that provoke our movements (physical and mental)" (Sutil 2015, 170). Situational kinespheres suggest the rules by which the agents and sounds can and should move within a given musical situation. To borrow Norman's concept of affordance—"the perceived and actual properties... that determine just how the thing could possibly be used"—there exists an affordance of the situation (Norman 2002, 9). When encountering a new interface or instrument, we might ask, "How can I use this thing?" When attending a musical concert for the first time, we might ask, "How should I act?" Both questions consider an observation of properties and behaviors that help facilitate an understanding of the interaction(s). Embedded within the design of an instrument and a situation are cultural and historical factors that nudge the performance in one direction or another. The situational kinesphere expands and contracts like that of the body kinesphere, a dynamically changing container that houses the music, its culture, and its agents.

By using kinesphere to describe the musical situation, we reference a body that extends beyond the material and biological body of the musical performer. The situational kinesphere ref-

[2]The *movement of a situation* differs slightly from the situational kinesphere. The situational kinesphere is the spatial container that envelopes and influences the musical setting. The movement of a situation dynamically unfolds within this setting, reaffirming or reshaping the kinesphere.

erences a dynamic body functioning within a larger environment. Johnson (2007) describes five levels of embodiment to conceptualize the full realization of the human body (274-8). The body is at once biological, ecological, phenomenological, social, and cultural (ibid.). The most common mode of thinking about body is the *biological* body, that is, the material, the "whole body" of flesh-and-blood that "make possible the qualities, images, feelings, emotions, and thought patterns that constitute the ground of our meaning and understanding" (ibid., 276). This physical body is commonly placed in relation to the *phenomenological* body – the "body as we live it and experience it" (ibid., 276). Yet, as has been shown in musical practice, the body is simultaneously an "organism-environment" (*ecological*) that partakes in "intersubjective relations and coordinations of experience" (*social*) that are impacted by "cultural artifacts, practices, institutions, rituals... that transcend and shape any particular body and any particular body action" (*cultural*) (ibid., 276-7).

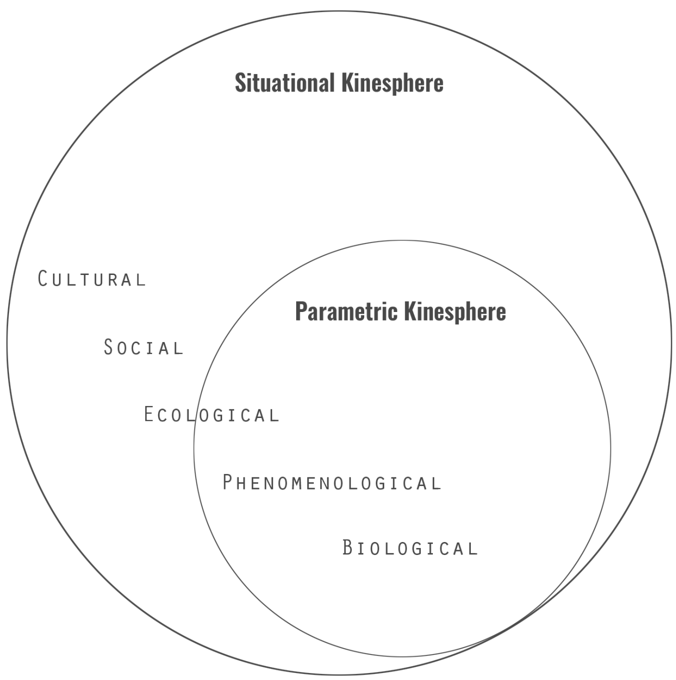


Figure 2-8: Situational and parametric kinespheres overlaid with Johnson's five layers of embodiment as each relates to the two kinespheres (Johnson 2007)

The five layers of embodiment may be viewed within the paradigms of control (Figure 2-8). The performer's body actuates sensors that feed musical controls—the physical and proprioceptive awareness that build the instrumental paradigm of its parametric kinesphere. The environment and institutional history further enact structures (situations) that our musical bodies must navigate. In practice, our bodies may or may not be conscious of these two control paradigms (Gallagher 2013). Parametric kinespheres and situational kinespheres account for expanded conceptions of body in DMI performance, and for the DMI performer, there resides a third *paradigm of control* shadowing one's actions. Hidden within the parametric kinesphere, inside software, moves an invisible digital body.

2.3 The Hidden, Digital Body: Data

Every DMI depends on digital control information (0s and 1s) for its sound. Many composers and authors have explored how digital information is gathered, modulated, and mapped onto sound.[3] For alternate controller DMIs, that digital information is primarily activated by the performer.[4]

Communication theory in the 1950s posited that signals transmit physical activity (Cherry 1957). The recognition of performer as signal has been shown as early as telegraph operators, who "could recognize the sender of a Morse code message only by means of temporal variations (modulations) in the Morse signal that are idiosyncratic to each operator" (Cadoz et al. 2000, 72). Resting within every parametric kinesphere is a trace of the body. Signals embody the performer without notation; signals carry the physical meaning of the performer directly. With digital computing, electrical signals function as a string of bits, a sampled and quantized representation of its physical counterpart. The aggregate of these bits form the movement phrases and trace forms of the body over time. This is the hidden body in data.

This *new* digital body takes shape through software and through digital sound. We are listening to our old body in a new way. We hear the moving body as an electrical turned digital signal that steps between the parameters of sound and space. These digital signals act as the presence of our bodies even as the perceptual distance between body and sound increase.

[3]There are complete journals (i.e., Computer Music Journal) and conferences (i.e., New Interfaces for Musical Expression (NIME)) dedicated to addressing the various topics of digital inputs, mapping, and outputs. There are too many to cite here.

[4]For context clarifying the performer including references, see Chapter 1.

While data signals may be immediate, a “direct physical impulse encoded as a signal” (Sutil 2015, 187), digital systems introduce a tradeoff between information and control. David Rokeby explains, “By increasing the amount of filtering that is applied in the perceptual process that the interactive system employs, the designer increases the reliability of the resulting information and therefore the unambiguity of control, but at the same time, the richness of that information is reduced” (Rokeby 1995, 149). Control comes at a cost, stemming from choices surrounding the performer, the technology, and the music.

The negotiation of a digital body can also take time to learn. Mackay (2000) describes this subtle evolution through the concept of “co-adaptation,” whereby one adapts oneself to technology just as one modifies the technology for one’s own use. As one contorts one’s body in learning how to play a new instrument, there is an understanding of how to adapt the instrument to become part of oneself (Davis 2016). As with acoustic instruments, playing an alternate controller DMI involves “an interrogation of body schema.”[5]

For signal theorists like Colin Cherry (1957), communication requires a selection or “discrimination” of signal. In music notation, composers select what information to show and when, so that a performer may recreate the signal. Too much information and the performer is incapable of accurately recreating the signal. Too little information and the signal may be inaccurately recreated by the performer.

Like music notation, DMI data is a reduction of information, both in terms of ‘control’ and choice. The performer’s body, which persists as data, is actively discriminated against by technology and composer; the *filtered* selection of the performer’s body signals is what trickles down into the sounds we hear. Some of these control filters are deliberate, while others come embedded in the technology.

Music notation and data extraction are both reductive signal processes. Both strive for a meaningful reduction of information. However, music composition differs from most engineering tasks in that composition does not always aim to improve signal fidelity. Music that incorporates digital data, specifically composition for DMIs, pursues choices about data (e.g., signal selection, sampling rate, sensor type, mapping) that further aesthetic identities, identities which may rub against issues of noise reduction and fundamental principles of design.

[5]Kevin Davis, phone interview by author, January 3, 2018.

Research into sensors and digital inputs for DMIs has been widespread (Miranda and Wanderley 2006), and websites like SensorWiki.org attempt to collect this research into a central location.[6] Notions of control and choice over information direct questions about digital inputs and their corresponding digital signals. What signals should be used? How many signals are necessary? What information is relevant and when is it relevant? Just what controls what? These and related questions account for the body without an explicit acknowledgement of the body's physical limits or its kinesphere. That is, one may cavalierly control how the physical body moves without heeding the performer's presence and their power to signify the digital signal turned digital sound.

Alternate controller DMIs that have been previously discussed require the body for their input, but it is digital data that can alter and ultimately usurp the body's role in the process. Like galvanic charges that rewire electrical signals sent into the body, the instrument may activate the body instead of being activated by it (Elsenaar et al. 2002). Digital sensors reduce rich body signals, and the instrument controls and their affordances (physical properties/boundaries) push certain types of interaction potential between the performer and her instrument. Authors often distill these musical interactions down to an instrument's ease-of-use (Jordà 2004; Vertegaal et al. 1996),[7] expressive capability (Christopher et al. 2013; Jordà 2001), or control/mapping functions (Bevilacqua et al. 2005; Hunt, M. Wanderley, and Kirk 2000; Hunt, M. Wanderley, and Paradis 2002). Others, like Calegario, M. M. Wanderley, et al. (2017), attempt to leverage rapid prototyping to assess interactive possibilities.

Design methods and interactions aside, the situation, the body, and the software ascribe a complexity to the DMI that cannot be ignored. Some, like Croft (2007), acknowledge the complexity of performer-instrument relationships, and Croft (ibid.) and Hardjowirogo (2016) make a unique case for a set of conditions in the context of electronics. The body as digital data serves as a paradigm of musical control, and unless the body is actively considered, the body will continue to fall prey to the choices and filters of engineers, instrument makers, and composers. As DMIs continue to employ the performing body, we should continue to consider how our "geometries in motion" (Sutil 2015, 205) function as part of the musical equation.

[6]Sensor Wiki, http://sensorwiki.org/ (accessed February 6, 2018).

[7]Jordà goes further, describing efficiency and learning curves of musical instruments (Jordà 2004).

Although signal reduction, body potential, and instrumental affordance complicates how we might understand the performer-instrument relationship in DMI performance, the digital body of data originates from simple structures. Regardless of the number of input systems or data streams that constitute a given instrument, we may describe the underlying structure as built from two basic data types: discrete and continuous. How a composer or performer considers performance-software changes through these digital data structures begs a closer look at the data types of the DMI.

2.3.1 Data Types: Discrete and Continuous

Instrumental sound deals with two physical actions: a momentary action and a modulating action. The two digital data types—discrete (0/1) and continuous (0.0 1.3 2.1 3.6 2.5 2.4 4.9 etc.)—model the physical actions, or interactions, between the performer and instrument. Momentary events (string plucked, key pressed, drum hit, etc.) and continuous events (windbag press, breath exhale, string slide, etc.) often occur together contemporaneously within the space of a sound. There may even be multiple actions of varying length. Collectively, these momentary and modulatory actions aggregate over the course of time to form the controls of musical sound—the controlled exhale of breath, its vibrato, the amplitude changes that occur during a selection of notes, their slurring, a staccato turnaround of double-tongued 32nd notes—a set of body actions interacting with its musical instrument.

Previous authors have addressed digital instrument and sensor data. Pennycook (1985) charts the timing of performance data on real-time music systems (269). Bongers (2000) links interaction modalities with electrical sensors in the context of DMIs. Patton (2011) charts "data stream typologies" in relation to sensing technology (19). Miranda and Wanderley (2006) unpack sensors, signal acquisition, and signal conditioning examples. Irrespective of sensor or data stream, in terms of musical control, the data may be understood in terms of an event (discrete) or a modulation (continuous).[8]

The combination and recombination of discrete and continuous information, combined with the performer-instrument interactions of the parametric kinesphere, build up the complex struc-

[8] Of course, multiple control structures exist in software (If/else, ternary operators, for loop, etc.) for mapping data onto musical outputs and control states.

tures, patterns, and ideas which constitute the musical architecture of sound control on DMIs. This is the ecology of DMIs. The situational and parametric kinespheres, combined with software control states help form the complex and dynamic relationships between body and sound, performer and instrument, action and control.

2.3.2 One Button One Fader (OBOF)

To research the ecology of DMI control through the basic digital data types (discrete and continuous), I built a custom controller that consists of a single button and a single fader, aptly called One Button One Fader (OBOF) (see Figure 2-9). While the varying combination of discrete and continuous data may be put together to form more complex and perhaps more interesting patterns, the basic physical controls pose a challenge to mapping. Rovan et al. (1997) discuss "divergent" mapping strategies, where one control handles multiple parameters at once (69). The common "one-to-many" mapping approach may solve conditions for a single control state, but a DMI may need to be extended to include multiple control states (M. Wanderley 2001), lest a single mapping paradigm make the instrumental interface (i.e., OBOF) something of a one trick pony.

Croft (2007) discusses the problematic space of mapping body to electronic sound in the context of live performance. His conditions for instrumentality support the complexities of the performer-instrument relationship, something that, in software, multiple control states can address. For example, Waisvisz's "scratch" mode on The Hands changed the instrumentality of his DMI with a push of a button.

The physical constraint of using only one button and one fader requires a conditional software architecture to aid the performer in shifting between control states (or material) in order to tease out more ideas (read expressivity) from a simple two input controller. For example, by employing hysteresis gates at the edge of the fader's maximum and/or minimum range, the continuous fader may contain up to two event triggers within its bounds. Multiple condition architecture enables the performer's ability to effect change by allowing more controls from basic inputs.

In Audio 2-1, a performer selects and scrubs through multiple audio samples within a single

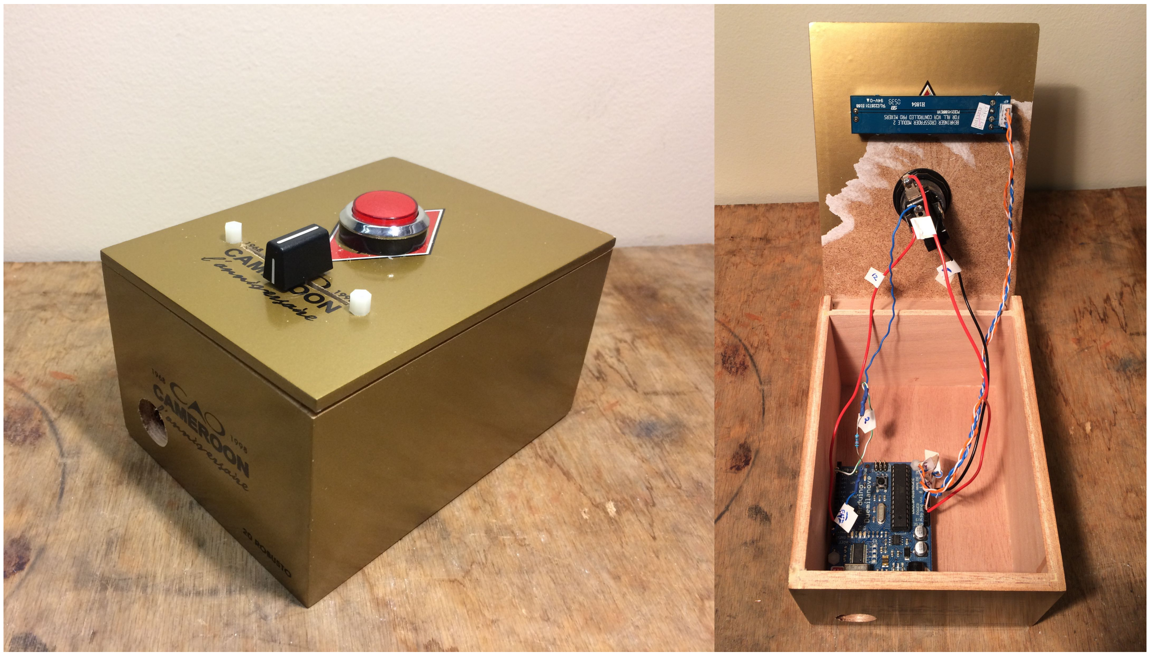


Figure 2-9: One Button One Fader (OBOF) custom controller (2017)

control state on OBOF. The basic controls of the single control state are as follows:

- button turns audio on/off
- fader scrubs through playback rate
- fader edge as hysteresis gate, changing the sample at random
- fader direction controls forward/reverse playback

Audio 2-1: *Fader Rate* example performed on One Button One Fader. All sounds are triggered and controlled by OBOF.

Another OBOF etude, *MG-2*, works through several control states on top of an underlying global state (Audio 2-2). Various combinations of button and fader events cycle through the control states and actuate different controls for each state. For example, the temporary on/off button turns Sample Bank 1 volume on/off with playback rate controlled by fader movements. In control state one, moving the fader completely to the right loads a new sample into Bank 1 with a hysteresis gate. The performer triggers the next control state by moving the fader to the left, holding the button down, then pulling the fader completely to the right (a combination of compound arguments, like that of a secret move for a video game controller).

OBOF also controls the slow modulation of the global background sound coming from a second sampler module. The module morphs the duration of samples and playback across sixteen voices. The OBOF controls playback rate and loop length of these samples, where holding down the button for three-plus seconds changes the Rate and Length of these two parameters in the second sampler module in relation to fader position.

Audio 2-2: *MG-2* performed on One Button One Fader. All sounds triggered and controlled by OBOF.

The shift in control paradigm that happens with OBOF between control states resides within the parametric kinesphere. Physical controls actuate these software changes. The road map to each shift must be known or learned, just as alternate fingerings or extended techniques on acoustic instruments must be learned and practiced.

This chapter has discussed how the situation, the relationship between body and interface, and the software of a DMI press upon the performer and her choices in musical performance. The moving body, expressed as signal, relays its presence in software. However limiting the controls may be, in live performance, the body (its relationships and its presence) remain in play. By understanding the paradigms of control through the body, we may more plainly see the choices of input, mapping, output, and temporal modifications of mapping that occur within a musical performance (a performance that contains a human performer on stage). The three paradigms of control help reveal spaces within the musical work, spaces that contain choices intentionally chosen or subconsciously *nudged* by additional forces (Thaler et al. 2009).

The next chapter describes software tools emanating from the paradigms of control; functions that tease out control possibilities from buttons and faders to assist the response of a performer in digital electronic sound. The parametric kinesphere and the hidden body of data help harness the power of data manipulation by signaling how one may control the moving body of the performer. By artfully manipulating the encoded data signals of the body, we may amplify the expressive capacity of movement. Such an *expression toolkit* would further tie the physical body to the musical body.

Chapter 3

Expression Toolkit

> For musical purposes, in the class ANY SOUND, almost all timbres are uninteresting, and many timbres are feeble or ugly. . . . It is VERY HARD to create new timbres we hear as interesting, powerful and beautiful.
>
> Max Mathews (M. Mathews 2017)

Expression Toolkit is a digital music composition toolkit. The toolkit includes data modification prototypes, objects and functions, control paradigms, and composition ideas that help one formulate musical possibilities from discrete and continuous control signals (Figure 3-1).

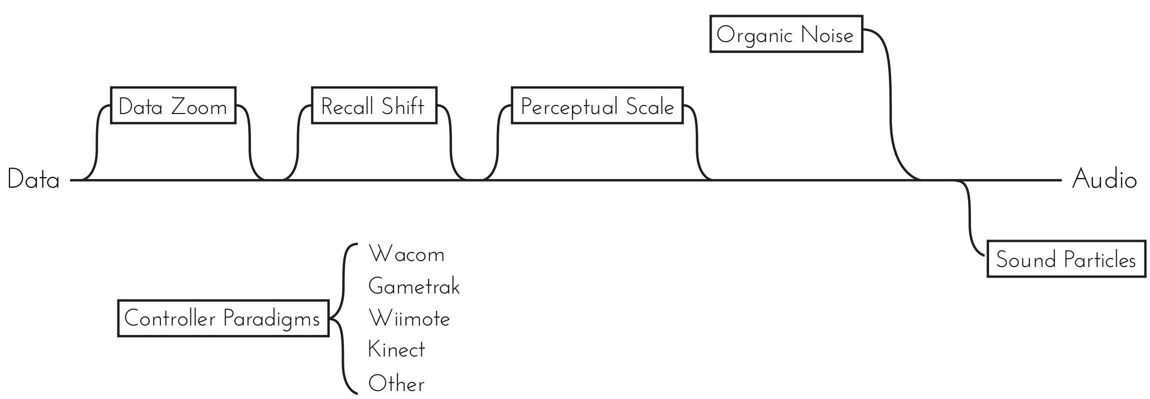


Figure 3-1: Modular overview of features in Expression Toolkit

I built the toolkit to aid live performance on stage and in the studio. Because compositions and sensors may utilize various software, the toolkit includes objects and functions for the Kyma and Max/MSP environments. All of the tools and ideas can be integrated into other audio environments, and some involve multiple softwares to achieve their desired result. For each tool, I will discuss the object/function in relation to its audio environment's specific publishing framework—Class Prototypes and Sounds for Kyma and Packages and Abstractions for Max/MSP. Each class prototype or package is modular, that is, each tool may be integrated separately or installed as a bundle (see Appendix B). Together, Expression Toolkit prototypes and packages form the author's own foundation for working with digital music, especially composing with alternate controllers. Expression Toolkit shapes an approach to working with DMIs.

3.1 Data Zoom

Magnification enables focus, detail, and exploration. *Data Zoom* is a term for magnifying, and exploring in greater detail, a finite range of data. Data zoom is used quite often in computer applications. In Microsoft Word or Adobe Photoshop, for example, one may zoom the view screen (e.g., 125%) in order to inspect a smaller region (of words or pixels) in greater detail. Figure 3-2 depicts an enhancement of the left side of the painting, revealing more detail within the same amount of screen real estate.

Figure 3-2: Data Zoom on a portion of Salvador Dali's *Dream Caused by the Flight of a Bee Around a Pomegranate a Second Before Awakening* (1944)

Data zoom may be applied to any stream of numbers. For example, one may map a fader to move between 0-1 and with a change in control state, scale the same fader to output a smaller range (e.g., 0.0 — 0.1; 1/10 scale of its original range). While simple in concept, data zoom is a powerful tool. If data controls sonic parameters, then the control enables us to literally 'zoom-in' and focus on detailed sound modification. Data zoom, then becomes a way to explore sound space vis-à-vis parameter space.

Data zoom may be considered a type of "vector model," where any number of synthesis parameters are assigned to a controller, which may be momentarily re-centered (using a switch or pedal) around a new point of interest (Dahlstedt 2009, 230). Typically, any shift in control state includes a shift in control position in order to enable fine resolution movement around the new, temporary center point. The basic concept of data zoom requires two controllers for the task: a continuous fader to move through both the normal and zoom ranges and a button to trigger the zoom.

A basic data zoom function works like this: whenever the zoom button is depressed, we reduce the digital scale of the continuous fader while maintaining the physical scale of the control. That is, a full movement on the physical handle now adjusts a fraction of its digital range. In order to take into account the current position of the fader at the time of zoom, we sample and hold the current location of the fader as our new zoom center location and offset the position of the zoom to this location. The magnification of data-zoom is an exponential value, because with a zero exponent (e.g., $10^0 = 1$), we can use a button press (binary 0 and 1) to create a simple on/off zoom function of varying magnitude. The magnitude of the zoom may be altered with a change in the exponent; for example, Figure 3-3 depicts a 10x data zoom and Capytalk 3-1 implements this 10x data zoom control for the Wacom tablet.

```
(!PenX / (10 ** !PenButton2)) + ((!PenButton2
sampleAndHold:  (!PenX - (!PenX / (10 **
!PenButton2)))) * !PenButton2)
```

(Capytalk 3-1)

In Figure 3-3, Pen X of the Wacom tablet is the continuous data that is magnified and the secondary pen button toggles the zoom on and off. !PenX is scaled down whenever !PenButton2 is depressed (by a power of 10). If data zoom is enabled, we add back, or offset, !PenX's location from when !PenButton2 was pressed. In order to take account of the actual pen location on the tablet, we also subtract !PenX's sampled location at the same order of the zoom. Lastly,

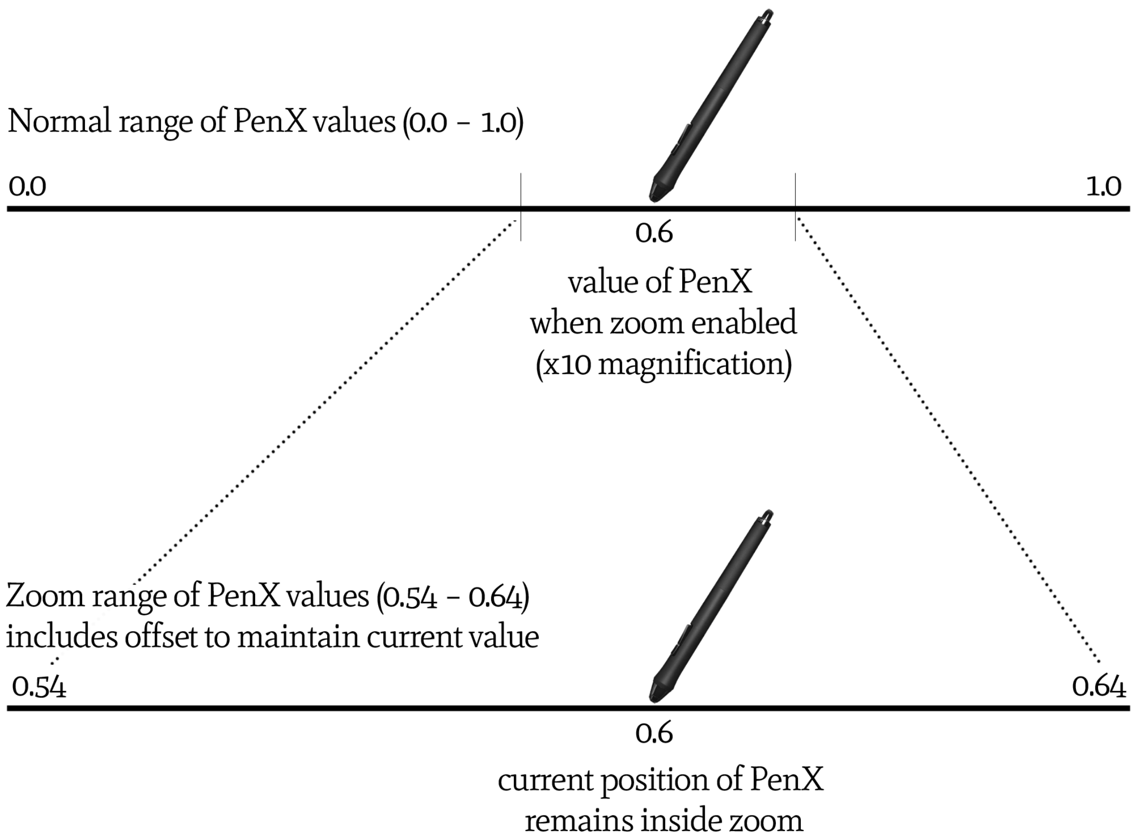


Figure 3-3: 10x data zoom function on Wacom tablet. When user enables zoom, the current value is saved and offset to maintain current position. The range of the data is scaled by the zoom magnitude (i.e., 10x). The range shifts to account for the current location of the pen, so that data doesn't jump, resulting in a smoother transition between zoom and normal modes.

we multiply this offset by !PenButton2 so that when the button becomes 0 (zoom off), the zoom offset no longer affects !PenX's initial, non-zoom state. Thus, when !PenButton2 is in an unpressed state (0), the Capytalk reduces to (!PenX / 1) + 0, or simply !PenX.

Audio 3-1 sounds data zoom as it is applied to scrubbing through the time index of an audio file, James Brown's *I Got You (I Feel Good)*.[1] Performed on the Wacom tablet, the Time Index parameter is linearly mapped to !PenX and the Frequency parameter is mapped to !PenY. Amplitude is non-linearly mapped to !PenTiltY. Without magnification, the playhead position of the 2-minute 44-second audio sample is mapped across the 8 and 13/16 inches of the Wacom tablet's X-axis (!PenX); even small adjustments of the pen can sound like high-speed fast-forwarding. By holding down !PenButton2 to enable data zoom, the 10x magnification now compresses 16.4

[1] James Brown, *I Got You (I Feel Good)*, 20 All Time Greatest Hits!, Polydor 314 511 326-2 (CD), 1991

seconds of audio index time across the same physical distance (8 and 13/16 inches). With the shorter duration of time that may be traversed across the full horizontal axis of the tablet, data zoom allows vocals, drums, and other instruments to become audibly recognizable.

Audio 3-1: Data Zoom applied to the TimeIndex of an audio file, James Brown's *I Got You (I Feel Good)*. Performed with the Wacom tablet.

3.2 Recall Shifting

Recall shifting is a technique to sample and reexamine/replay input data. Recall Shifting is different from Fiebrink (2009) and Françoise et al. (2014) who implement machine learning to recognize patterns of trained data. Instead, recall shifting is about the exploration of data played within the last M-samples (or M-seconds of time). Thus, the performer has access to a short-term memory of data, and he/she defines what is important by storing data in the moment of live performance. By sending performer's input data into a buffer of M samples (see Figure 3-4), we enable the performer's ability to recall and reexamine his/her past performance gestures.

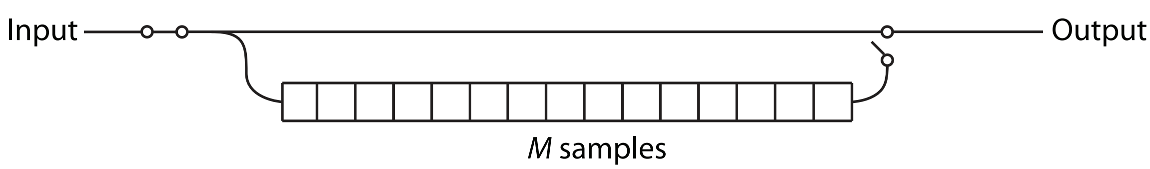


Figure 3-4: Data buffer *M*-samples long with input/output switch. Array index loops at control rate.

Replaying and exploring a musical phrase is commonplace in music. For example, Maceo Parker's solo in *Shake Everything You Got* deploys rhythmic play on a sequence of notes that ascends chromatically (Audio 3-2). Like acoustic musicians, performers of DMIs may repeat musical actions to replay phrases. With the ability to store and recall performance data, input numbers may be shifted and recalled just like sonic material that can be revisited and rearranged (e.g., a sequence of notes). Since DMIs use input data that represents actions by the performer, storing and re-sampling data is, in a sense, storing and re-sampling performance actions. There are three implementations to this idea, all of which are similar in execution, but differ in how data is stored and recalled—*Simple Storage/Control-Rate Recall*, an array or array list with action-based storage of samples and basic playback at control rate; *Control-Rate Storage/Basic Recall*, an array or array list with storage at control rate and basic methods for retrieving and playing back data; and *Feedback Delay Recall*, a short delay line that stores and playbacks data at control rate.

> Audio 3-2: Maceo Parker vamps and manipulates a short pattern of notes in his chromatically ascending solo in *Shake Everything You Got* (Parker 1992).

Simple Storage/Control-Rate Recall

Simple Storage/Control-Rate Recall is a semiautomatic push-pop array that requires performance actions to add to the array, yet plays back its data at control rate (Figure 3-5). Since the playback of data is at control rate, storage is determined by the user during performance. By implementing a short array for recall, a performer can treat the array as a performance bank, with the use of a discrete trigger to 'store' pitches, presets, or moments of sonic interest. With recall at control rate (e.g., BPM rate), the memory buffer may serve particular contexts, like dynamically evolving pitch sets. Audio 3-3 uses one fader to control the playback (pitch) of sample playback and one button to push the fader's positions into a small (four-slot) memory buffer. Using BPM rate memory recall for randomized, non-sequential index values, the memory buffer effectively creates a repetitive playback of a short, sequence of notes.

> Audio 3-3: One button, one fader control of a short term memory buffer used for pitched playback of an audio sample. The four index push-pop array feeds the frequency of a sample that is re-triggered at BPM rate. Performed on OBOF.

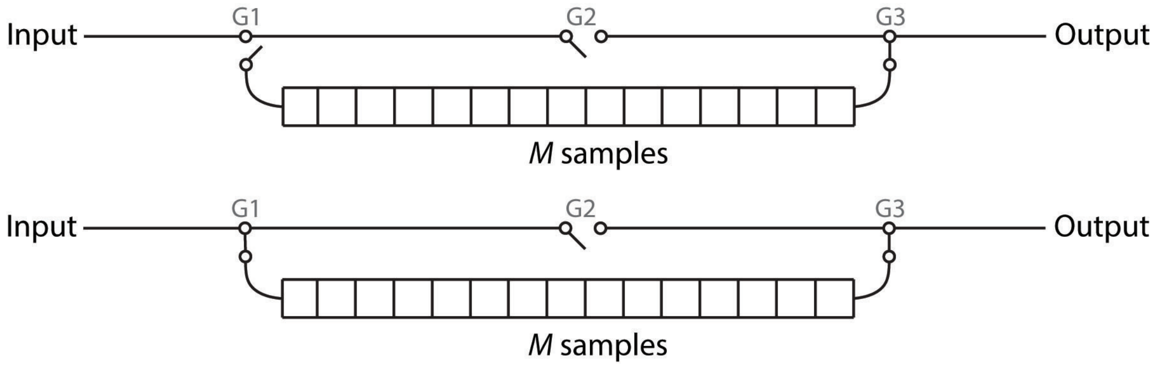


Figure 3-5: The top image depicts the default state of Control-Rate Recall; gate 3 is always on, and gate 2 is always off, so that all control data comes from the M-sample array. A button push by the performer opens and closes gate 1 in order to feed a new number into the push-pop sample array (bottom image). Audio 3-3 sounds an example.

Control-Rate Storage/Basic Recall

Control-Rate Storage/Basic Recall is an array or array list that continuously stores M-samples of data at control rate and lets the performer shape the playback of the data during performance (Figure 3-6). Storage slots can be added using multidimensional arrays or increasing indexes within a single array. By implementing the use of a discrete trigger for recall, the performer may ‘capture’ or ‘go back’ and repeat the moment of sonic or gestural interest. Performers may shift the recall playback by varying the length and start-offset of the data, or even cycle through previously saved buffers. *Great Speeches* (2015) is a composition that utilizes Control-Rate Storage/Basic Recall (Audio 3-4). The piece (for 10+ computers) recalls sequences of time positions in audio buffers played back from computer speakers, with all computers running the same composition application.

Audio 3-4: Excerpt of *Great Speeches* (2015). The example documents a live performance with 250 undergraduate students (and their computers) performing. Recorded at University of Virginia, Charlottesville, VA in 2015.

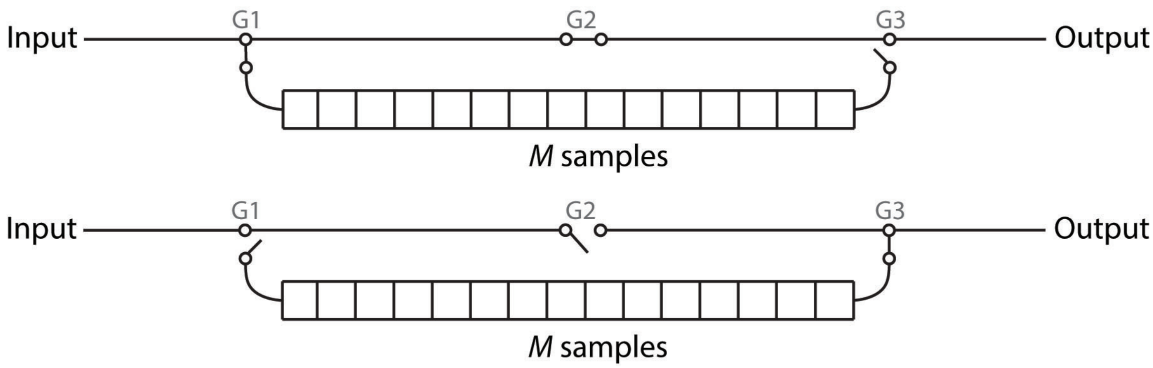


Figure 3-6: The top image depicts the default state of Control-Rate Storage; gate 2 is on to pass through performance data, and gate 1 is on by default in order to 'listen' and save performance data into short-term memory. A single push-button closes gate 1 to save input data for later. The data isn't recalled until a second push-button opens gate 3 and simultaneously closes gate 2, in order to 're-perform' data (bottom image). Audio 3-4 sounds an example.

Feedback Delay Recall

Feedback Delay Recall uses a short delay line that stores and playbacks data at control rate. By turning feedback to 100% and shutting off the input to the delay when recalling data, a performer creates a mini memory loop buffer, which is similar to Ableton Live's beat-repeater effect. The data array is treated as an M-sample memory buffer. Recording sensor data occurs in the 'background' with no output. When a performer hears an interesting sound that is a result of this incoming data, she may use a discrete trigger to cut off input to the delay, and simultaneously switch on the delay output (see Figure 3-7).

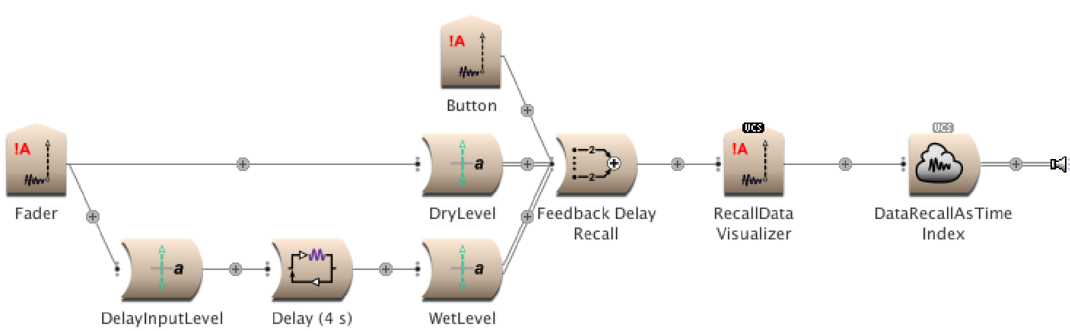


Figure 3-7: Feedback Delay Recall inside Kyma, where DryLevel and DelayInputLevel are cut when button is triggered on, and simultaneously increases the WetLevel and Delay feedback to 100% in order to create a memory loop of previous fader data. The example data controls the TimeIndex of a file using granular synthesis (see Appendix B).

Musicians like Reggie Watts take advantage of similar sampling technology, but for live audio loops.[2] Audio is fed into memory buffers or delays, that are stored, recalled, and then layered. Feedback Delay Recall-Shifting loops data instead of audio, which offers different possibilities in the sculpting of sound. For example, a simple audio delay does not allow one to independently alter the audio recording in the delay line. One may place effects after the delay to alter the audio recording or re-record into the delay, whereas looping data can be manipulated before synthesis, which effectively alters audio output before the addition of any audio effects.

Audio 3-5 uses a feedback delay for its data, and since the data loops and controls a distinguishable audio feature (time index), the result can be heard as an audio loop. The release of the button enables new fader values to begin overwriting values in the delay line. The time of the delay is shown in Capytalk 3-2, which is BPM proportional to the maximum delay time of 4 seconds.

```
((60.0/!BPM) * !Beats * 0.25 * (!Divisions / 64))
```
(Capytalk 3-2)

Audio 3-5: One button, one fader control of a delay used for sampling fader values. Fader values control the time index of an audio file using granular synthesis, but on hold of the button, the delay loops the last section of data, playing this data back in relation to the current BPM time. Performed on OBOF.

Audio 3-6 goes one step further by shifting how the data is mapped upon its recall. When the performer loops data, the delay also alters the density, filter cutoff, and panning of granular synthesis independent of its 'dry' effect mapping.

Audio 3-6: Sound parameters that alter mapping upon data recall. Performed on OBOF.

---

[2]Reggie Watts, "Reggie Watts lets Conan O'Brien play with His Looping Pedal," YouTube, rebroadcast of *Conan*, episode 958 (aired November 16, 2016). https://www.youtube.com/watch?v=3sCN9WdhvN4 (accessed February 1, 2018)

3.3 Perceptual Scaling

Scaling is a process used frequently within sensor conditioning, and is one of but several methods for modifying data, including: offset, interpolation, thinning, and smoothing (Stolet 2011). Scaling data may include linear and non-linear transform functions and may even be used to aid event-based triggers (e.g., hysteresis).

Sound is a medium that is perceived non-linearly. For example, frequency to pitch and amplitude to loudness have logarithmic relationships (Hall 1991). In these psycho-acoustic domains, non-linear scaling of input data may assist with matching the perceptual domain to the controller domain (i.e., perceptually scaling the input to output). While both linear and non-linear controls include the possibility of achieving the same sonic result, a non-linear control may present fewer motor-skill challenges to the performer in achieving the desired sonic result, especially for a control mapped to a logarithmic domain like pitch.

For example, Audio 3-7 and Audio 3-8 integrate the same performance action, timing, and sound mapping of an input, but the singular difference of scale, linear and non-linear mappings, result in different sonic results. The two examples sound the perceptual differences between linear and non-linear scaling.

Perceptual scaling does not simply describe the implementation of non-linear mappings for matching psycho-acoustic phenomena. While mathematical equations help us achieve non-linear mappings, the practice of scaling for DMIs is as much about trial and error as it is about mathematical precision (for examples, see Chapter 4 and Chapter 6). Listening to and performing data with varying degrees of modification aids composer-performer perception of appropriate scaling, and these scales are not bound by strict phenomena and formulas. This is to say that the concept of *perceptual* refers to the subjectivity of the performer, the feel and sound of performance actions (in the context of DMIs), within the desired compositional context. Just as Audio 3-7 and Audio 3-8 sound out linear vs. non-linear scaling, any multiplicative modulations to data might sound different when mapped to the same sonic parameters; how data is scaled might require diverging performance movements in order to audibly correlate the sound.

Audio 3-7: Linear increase of fractal noise. Sound increases over two seconds and repeats three times.

Audio 3-8: Non-linear increase of fractal noise. Sound increases over two seconds and repeats three times.

Of course, not all perceptually scaled outputs need be consistently non-linear. For example, Sound Particles (Section 3.5) presents a linear panning output example, but only whose input is non-linearly scaled (Figure 3-13 and Audio 3-11). The perceptual scaling of the input-output mapping includes panning (the placement of sound in the stereo field) and the addition of a harmonic voice with each new linear output point.

While not every parameter requires non-linear mappings, my compositional work for DMIs compelled me to develop a more robust non-linear scale function due to its frequent and incessant use. *jpb.mod.scale* (Figure 3-8) addresses performance needs for DMIs using non-traditional, non-linear scaling equations. *jpb.mod.scale* is part of *jpb.mod.**, a Max/MSP package with ready-made data modification modules (Bellona 2015b). These modules address data modification of a one dimensional data stream. The *jpb.mod.scale* object includes several non-linear mapping types:

- exponential
- gaussian
- cosine
- crossfade
- bell
- inverted gaussian
- inverse crossfade

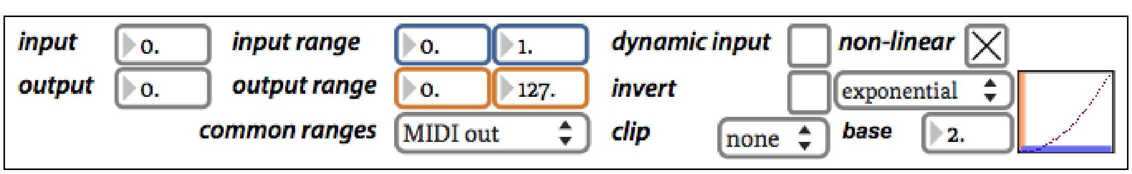


Figure 3-8: jpb.mod.scale object from jpb.mod.* Max package (Bellona 2015b)

Similarly, data may be scaled non-linearly inside Kyma. Non-linear scaling permeates throughout works for Distance-X (Chapter 6) and Expression Toolkit prototypes (Section 3.6). Two common methods for scaling in Kyma include wavetable multiplication (Figure 3-9) and Capytalk arrays implementing input@output points (Capytalk 3-3, Figure 3-10).

Wavetable multiplication in Kyma is similar to how *jpb.mod.scale* scales data—an input references a wavetable index for scalar output. In Kyma, this method requires two basic objects, CapytalkToSound, which plays control data at audio rate, and Waveshaper, which outputs any non-linear waveform amplitude (-1 to 1) at its corresponding index. Since the waveform table index matches the controller's range, the appropriate, non-linear data is output accordingly (Figure 3-9).

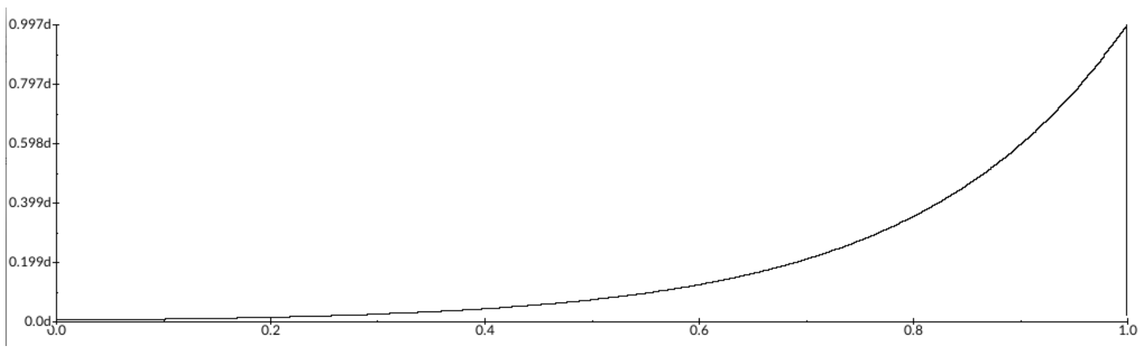


Figure 3-9: Non-linear scale using Kyma's Waveshaper Sound. The index value outputs an amplitude value for a waveform along an exponential curve.

```
!PenTiltY into:  #({-1.3@0} {0.2@0.2} {0.75@0.4}
{1.3@1})
```
(Capytalk 3-3)

Non-linear scaling that implements a Capytalk array of input@output points requires at least three data points. Capytalk 3-3 contains four input@output points. The first and last points encapsulate the general range of !PenTiltY, -1.3 to 1.3 respectively, and the two inner points shift the mapping into a non-linear output. Capytalk linearly interpolates between the points, but the result, shown in Figure 3-10, is non-linear. The non-linear mapping allows for larger performance movements for values 0.0–0.2, as more than half the fader focuses on this small value range. The X-axis of Figure 3-10 has been scaled to fit Figure 3-9 in order to help visualize the differences between each approach.

In summation, perceptual scaling assists the composer-performer in achieving desired sonic results while enabling her performance capacities. Controller data may include both linear

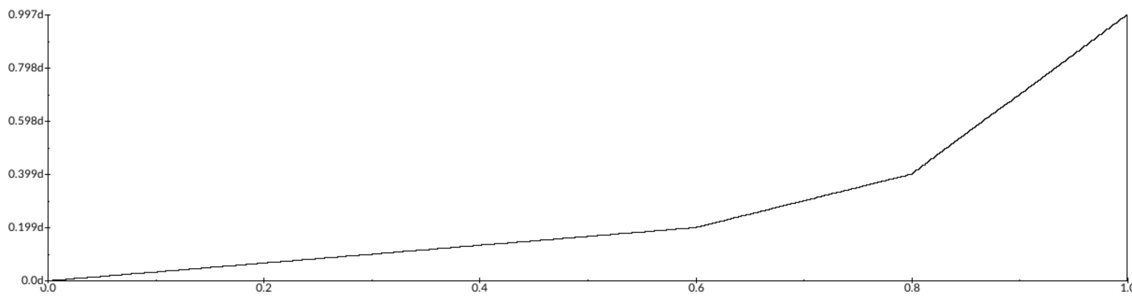


Figure 3-10: Non-linear scale using Capytalk into: #(), an array of four input@output points

and non-linear scales on its inputs and outputs; listening to the mapping in context of performance is paramount. By seeking to maximize the range of the performer's movements in order to achieve the most sonically interesting results, the DMI composer may discover perceptual scaling as beneficial to the compositional process.

3.4 Organic Noise

Computations on the digital computer are exact and precise, but human musical performance contains slight variations that we often overlook. Using computers to perform digital electronic sound makes plain the subtle variations in sound that a human performance qualitatively, and organically provides. By purposefully injecting noise, or non-deterministic variations, into control signals, we may enrich the sonic quality of performance and compensate for the computer's precision.

For example, the repetition of a computer playing an audio sample is static—there is no change to the material regardless of the number of times the computer repeats the material. In the acoustic world, however, repetition is not static. A performer striking a drum surface is subtly different each and every time, regardless of a performer's impeccable timing and measured force. That is, frequency and amplitude modulations exist in every physical hit/strike (the placement of the stick on the drum head, the amount of energy delivered, etc.).

Recording a single drum strike codifies these subtle variations in the recording and cannot be easily changed. The recording captures a single variation within its envelope. Thus, a computer playing back the same audio file repeats the same codified performance event. To the extent that hearing recordings can be easily recognizable (The Rolling Stone's opening snare hit for *I Can't Get No (Satisfaction)*), repetition of singular events may further become static and uninteresting.

Several methods exist to combat the *coldness* of file playback. First, one may playback different audio samples that contain slight performance variations. In the previous drum scenario, this method would require recording a performer striking a drum multiple times in order to organically capture the subtleties of performance. One may also account for these subtle shifts in performance algorithmically, through the slight alteration of various sonic characteristics of the sound upon playback (typically playback of a single file). For example, subtle shifts in frequency, attack envelope, and amplitude may aid the organic feel of sample playback.

The concept of playback variation is not new (e.g., MIDI swing), but the idea is important to DMI performance. Playback variation aids the organic quality of a DMI performance even when employing a human performer. For example, subtle pseudo-random noise may account for performance signal lost during the digital conditioning of sensors.

One example of organic noise at play may be heard in Audio 3-9. An audio sample is continuously re-triggered, and each playback trigger implements pseudo-random noise, offsetting attack, pitch, amplitude and panning of the sample in order to simulate organic playback. Time-based algorithms are used to generate the pseudo-randomization, as shown in Figure 3-11. Without random playback, the repetitive playback of a single audio sample remains static (Audio 3-10). By providing slight variations to the sound file upon playback, the variations mimic the performance style of a human—fluctuating components of the sound's shape (e.g., envelope, overall amplitude, and frequency)—while still retaining the strength of the computer in its exact and consistent timing.

Audio 3-9: Excerpt of *Bells Beating* (2016). The re-triggering of an audio file implements pseudo-random noise that offsets attack, pitch, and panning with each trigger in order to simulate organic playback.

Audio 3-10: The re-triggering of an audio file without any pseudo-random noise so that playback remains static and uninteresting. Compare to Audio 3-9.

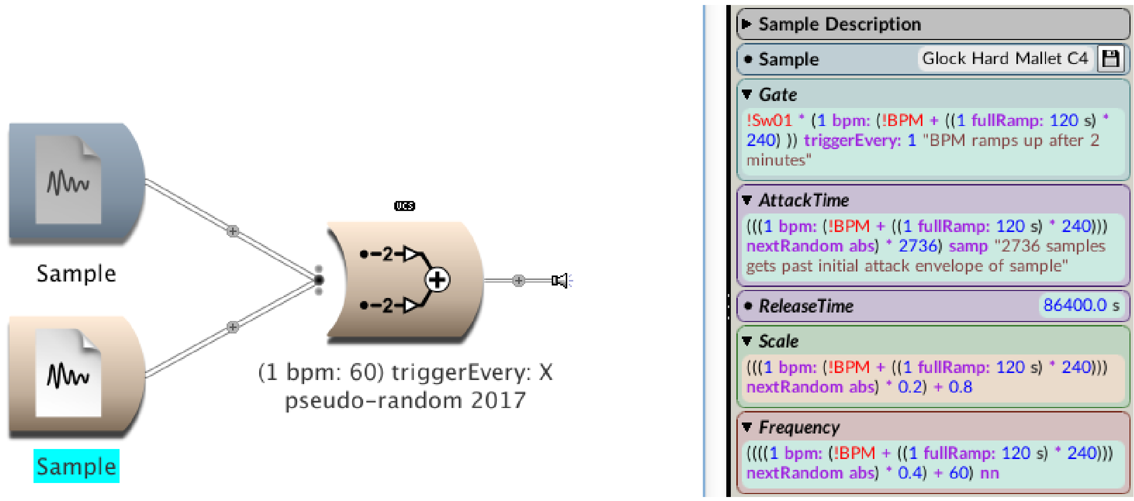


Figure 3-11: Playback of glockenspiel sample inside Kyma with pseudo-random jitter applied to amplitude and frequency parameters of a Sample Sound.

For pseudo-random variation, I built *jpb.noise* in Max/MSP to aid the generation of noise over time. While a full discussion of random number generation goes beyond the scope of this chapter, *jpb.noise* extends an external object, *randdist* by John MacCallum, which generates a gaussian noise distribution, similar to Perlin noise, at control rate (MacCallum 2009).[3] *jpb.noise* is part of the *jpb.mod.** Max package (Bellona 2015b).

3.5 Sound Particles

Particle systems are a common technique applied in computer graphics, typically used to create "fuzzy" objects like rain, smoke, or fire (Reeves 1983, 92). Instead of micro-managing each individual particle that creates the effect, a particle system is responsible for governing an array of hundreds or thousands of these small objects (Figure 3-12). Sound particles use the principle of a particle system to build a sound environment through an array of various sound objects in an acoustic space. Unlike basic granular synthesis that simultaneously plays back a segment of a single sound spanning a short time (i.e., 1 to 100 ms) (Roads 1996, 168), sound particles have more variable freedom within a musical system—each particle may play back from a bank of sounds, may have different amplitude envelopes, and may host any other number of variations

[3] This work makes use of software developed at the Center for New Music and Audio Technologies (CNMAT) at the University of California, Berkeley.

that individualize each particle within its audio environment. Sound particles share the same Class features (constructor, methods, etc), which help group the sound particles together within the sounded environment.

Figure 3-12: Example of a particle system of pixels rotating around a centrifuge. © 2013 Jon Bellona

Sound particles are a form of polyphony. Audio environments handle multiple voice assignment differently (e.g., poly∼ inside Max/MSP, Replicator inside Kyma); yet, multiple voices offer potential in creating dynamically rich textures, from timbre to soundscape, based upon the character features of each polyphonic voice. For example, we may spread a sound out within the stereo field as we increase the number of voices being played/heard, or we may create a full city soundscape through variations in sample selection, density, playback rate, location, reverb, movement, and additional audio characteristics in order to create the feel of a soundscape using a particle system.

Sound particles may serve composers as a sound design tool (Fonseca 2015) or a live performance technique. To outline sound particles in the context of DMIs, three examples are given below. These examples stem from compositions the author built for live performance using the Wacom tablet and Distance-X (Chapter 6). Each example will be discussed within the framework of Kyma using the Replicator Sound. Replicator creates two variables, ?VoiceNumber and ?NumberVoices, that assist in the dynamic control of each sound particle. Any Kyma Sound or parameter that comes before the Replicator (e.g., Panning, Playback rate, Sample file, Reverb, etc.) may become a dynamic part of each sound particle by using these ?VoiceNumber and ?NumberVoices variables.

Sound Particle: Pan Spread

Sound particles may help composers place sounds within a space. In the example below, sounds spread out in the stereo field starting from the center as the number of voices (particles) increases. Capytalk 3-4 spreads sound particles out linearly from center, based upon the increase of voices.

```
[Pan parameter]

0.5 + (((?VoiceNumber-1 / ?NumberVoices) *
((?VoiceNumber-1 mod:  2) * 2 - 1)) * 0.5)
```

(Capytalk 3-4)

In Kyma, the range of stereo panning is 0—1, where 0 is complete Left and 1 is complete Right. Starting with a sound in the middle (0.5), we sum the center point with a fractional modulation that increases with voice number (range -0.5 to 0.5), as shown in Figure 3-13.

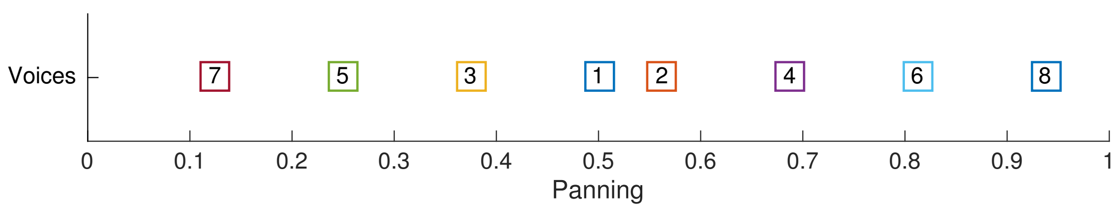


Figure 3-13: Stereo width by voice number

Thus, if the gain of each voice equals 1 (0dBFS), the sound particles comprise a chorus of voices panned from center outward toward both left and right speakers. Audio 3-11 pans five copies of a granular sound using this panning spread, and additionally parametrizes the gain for each particle. The number of particles heard increases with an increase of !PenY (a movement up through the Y-axis) on the Wacom tablet (Capytalk 3-5).

Audio 3-11: Sound particles using five copies of Kyma SampleCloud (granular synthesis) with panning controlled by VoiceNumber (Capytalk 3-4), and voices added through !PenY (Capytalk 3-5). Performed with the Wacom tablet.

```
[Amplitude parameter]

(!PenY gt:  (1/?VoiceNumber))
true:  (?VoiceNumber * !PenY - 1)
false:  0
```
(Capytalk 3-5)

Audio 3-11 was performed using the Wacom tablet. The pen begins in the center, granulating a sound, with !PenX serving as the time index of the sample. As the pen moves up in Y space, the number of voices introduced into the sound increases. Each additional voice is placed at an expanding distance from the center of the stereo field. !PenTiltY adds additional gain control. The sound utilizes !PenTiltY non-linear amplitude mapping (Capytalk 3-3) and TimeIndexScrub w/Data Zoom (see Section 3.1).

Sound Particle: Frequency Spread

Sound particles may be distributed in frequency space linearly (Capytalk 3-6) or logarithmically (Capytalk 3-7). Depending on the scale of frequency, the result can sound like a chorus of voices (Audio 3-12).

```
[Frequency parameter (2 octave range)]

default * ((?VoiceNumber/?NumberVoices) * 2)
```
(Capytalk 3-6)

For increasing by semi-tone or micro-tone with each voice, we convert the voice number into a logarithmic scale (Capytalk 3-7 or Capytalk 3-8).

```
[?VoiceNumber into Pitch Ratio (Chromatic)]

default * ( ((?VoiceNumber-1) / 12) twoExp)
```
(Capytalk 3-7)

```
default nn + (?VoiceNumber - 1) nn
```
(Capytalk 3-8)

Audio 3-12: Sound particles using five copies of Kyma SampleCloud (granular synthesis) with frequency spread across a 2 octave range (Capytalk 3-6). Additional controls include Data Zoom on TimeIndex (Capytalk 3-1), panning controlled by VoiceNumber (Capytalk 3-4), and number of voices present controlled through !PenY (Capytalk 3-5). Performed with the Wacom tablet.

Sound Particle: Low Pass Filter Cutoff

Akin to brass instruments, sounds may darken as the overall amplitude (energy) decreases.[4] Similarly, as sounds move further away, high frequencies start to roll off.[5] Thus, we may implement filters and number of voices to support and simulate the psychoacoustic phenomenon that sound increases in brightness and amplitude as sounds move closer (Audio 3-13).

```
[?VoiceNumber controls LPF Cutoff Frequency]

((!PenY gt:  (1/?VoiceNumber))
true:  ( (?VoiceNumber * !PenY - 1) into:  #({1@20000}
{0@100}) )
false:  100) hz
```

(Capytalk 3-9)

Audio 3-13: Sound particles using five copies of Kyma SampleCloud (granular synthesis) with the cutoff of a low-pass filter controlled by !PenY (Capytalk 3-9). !PenY also increases the number of voice present. Performed with the Wacom tablet.

Sound Particles within an Acoustic Space

With a sample bank and stereo reverb, sound particles may help composers dynamically position sound events within an acoustic space. Supplying each sound particle a location value effectively places the sound particle in 3-dimensional space, minus elevation (where the location value controls dry, wet, and low pass filter cutoff of a reverb unit). Additionally, sound particles receive stereo pan, volume, and frequency values. In Audio 3-14, a performer triggers

[4] Scott Wyatt, "Acousmatic Composition" (lecture, University of Oregon, Eugene, OR, May 1, 2013).
[5] ibid.

dynamic sound events using the Z-axis of the Gametrak, which occurs with every change in direction of the Z-axis (Capytalk 3-10). The Y-axis of the Gametrak sets the pitch ratio for each event with the value being sampled at the time of the event trigger.

```
[Triggering Samples by Switching Direction]

(!OSC_gtz_dir switchedOn) + (!OSC_gtz_dir switchedOff)
```
(Capytalk 3-10)

Audio 3-14: Sound particles using six copies of Multisample Sound running through Pan and Stereo Reverb. Each sound particle receives distance, stereo pan, pitch, and volume values independently to create a cluster of sound events within an acoustic space. Performed on Distance-X.

3.6 Controller Paradigms

Many of the controller paradigm prototypes described below are *behavioral* or *performative* mappings, that is, they stem from specific use-case scenarios of alternate controller compositions and performances. Each prototype includes a description and sound example. Links to access each set of custom prototypes may be found in Appendix B.

3.6.1 Wacom Prototypes

Figure 3-14: Wacom Intuous tablet

The Wacom digital drawing tablet (Figure 3-14), is an input controller that includes a pen and tablet interface. The high resolution of the X and Y space and access to pen controls (two buttons on hand, pen down, pen eraser, pen tilt, and Z-axis) make this controller highly versatile for performance contexts. The Wacom tablet is also native to Kyma—the device is plug n' play—furthering the ease with which one may integrate the Wacom tablet into sound design and performance. For a more detailed look, see Chapter 4 for several performance practice case studies that utilize the Wacom tablet as musical interface.

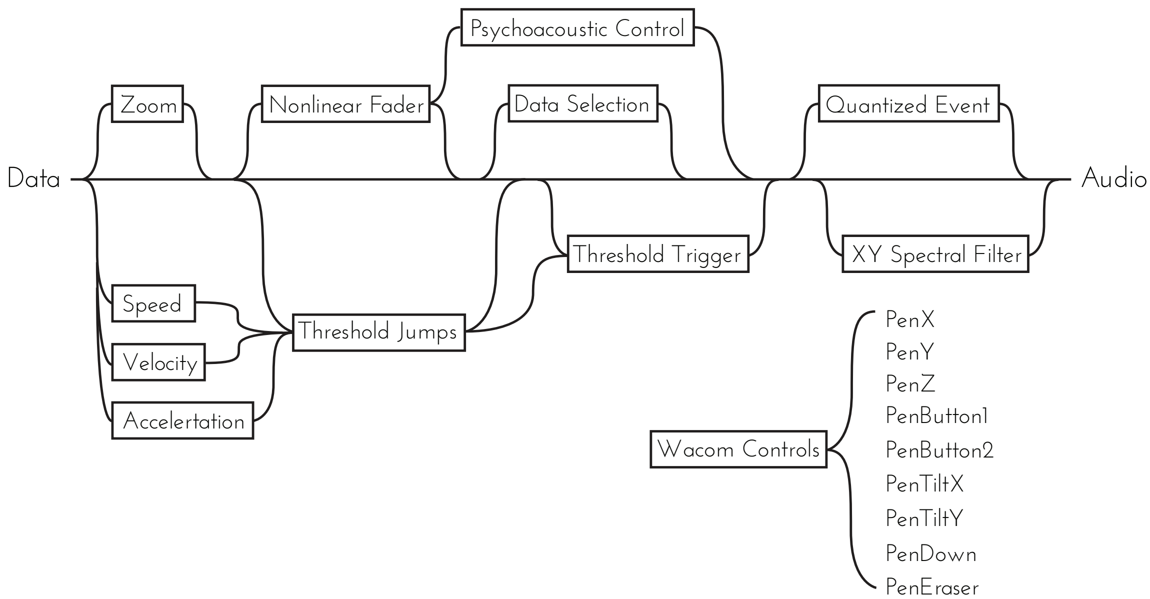
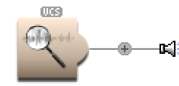


Figure 3-15: Modular overview of basic Wacom feature prototypes

Many of the Wacom prototypes described below are in relation to the input controller. For example, "non-linear amplitude" is a non-linear mapping for the tilt of the pen in Y-space the author uses regularly. Playing the Wacom using non-linear tilt to control amplitude allows for fine control over the dynamic range of sounds coming from the instrument system, and feels comfortable to the performer. While I outline Wacom prototypes here using Kyma, these controls may be translated to a variety of platforms (e.g., Max/MSP) or adjusted to fit the needs of a performer.

DataZoom: 2 buttons 1 fader

DataZoom magnifies a data stream using a gate. A single button/gate (i.e., !PenDown) tracks a data stream input (e.g., !PenX) when on, and holds the current value of the data stream input when off. A second button/gate (e.g., !PenButton1), magnifies the data stream by a magnitude of ZoomAmount (mathematically DataStreamInput/ZoomAmount). The zoom calculation also offsets magnified values in accordance to when the zoom function was first enabled (Audio 3-15). Capytalk 3-1 contains the full expression, and Section 3.1 describes data zooming in further detail.



DataZoom (2 buttons 1 fader)

Audio 3-15: The X-axis of the Wacom tablet scrubs through a sound file with DataZoom. Pressing !PenButton1 magnifies the TimeIndex parameter so more detail is exposed to the performer. Includes the introduction of harmonic sound particles with the Y-axis. Performed with the Wacom tablet.

DataZoom: 1 button 1 fader

DataZoom magnifies a data stream using a gate. A single button/gate (e.g., !PenButton1) magnifies a data stream input (e.g., !PenX) by a magnitude of ZoomAmount (mathematically DataStreamInput/ZoomAmount). The zoom calculation also offsets magnified values so that data centers around a saved data stream input value in accordance with when the zoom function was first enabled. Audio 3-1 employs the Wacom tablet to scrub through an audio file using DataZoom. Capytalk 3-1 contains the full expression, and Section 3.1 describes data zooming in further detail.

Non-linear Amplitude

Capytalk 3-11 non-linearly normalizes the general range of !PenTiltY, -1.3 to 1.3 respectively, to between 0 and 1. The non-linear mapping provides for larger performance movements between *ppp* and *mf* (values 0.0–0.3), as half of Pen Tilt focuses on this small value range. Audio 3-11 employs a non-linear amplitude mapping.

```
!PenTiltY into: #({-1.3@0} {0@0.3} {1.3@1})
```
(Capytalk 3-11)

Psychoacoustic Control: Amplitude into Reverb Dry/Wet Ratio

As part of achieving a psychoacoustic association between loud and close, quiet and distant, we may tether amplitude controls with the dry/wet ratio of a reverb effect (Audio 3-16). Using Capytalk 3-11 as the 0-1 controller with output set to !VerbController, the Amplitude parameter affects Direct Amount (dry), Reverb Amount (wet), Decay Time (where 0-1 is normalized between 0.01 and 4 seconds), and LPF Cutoff Frequency (where 0-1 is normalized between 1 and 15kHz). As amplitude increases, the amount of dry gain increases, while wet gain decreases. The wet signal peaks as the amplitude is close to the bottom (0.2), but as amplitude continues to decrease, the wet gain begins to decrease to further push the sound into the distance (Capytalk 3-12). The LPF Cutoff Frequency and Decay Time also have inverse relationships to dry signal, with Decay Time (Capytalk 3-13) and Cutoff Filter decreasing (Capytalk 3-14) as the sound becomes quieter.

```
(1 - !VerbController) into: #({0@0} {0.8@1} {1@0.25})
```
(Capytalk 3-12)

```
(1 - !VerbController) * 4 s
```
(Capytalk 3-13)

```
((1 - !VerbController) * 14000) + 1000 hz
```
(Capytalk 3-14)

Audio 3-16: Psychoacoustic control of a reverb effect. As the sound moves closer to the listener, the sound becomes louder and contains more high-frequency content. Performed with the Wacom tablet.

Quantized Event Trigger

Synchronized events can be useful, especially for metrically rigorous applications. A quantized button trigger can aid the performer in that a button press happens on the next quantized beat, regardless of timing before the beat (Capytalk 3-15). Similar to Ableton Live's Clip Launch Quantization control,[6] a button press fires its trigger upon next quantized value, and the button does not need to be held across the beat to activate its trigger. An alternative method is to use alignWith: (Capytalk 3-16).

```
((1 bpm: (!Trigger initialSampleAndHold: !BPM))
triggerEvery: !Beats rounded) * (!PenDown setReset:
!Trigger)                                              (Capytalk 3-15)

!Trigger alignWith: (1 bpm: (!BPM / !Beats rounded))   (Capytalk 3-16)
```

When pressed, !PenDown is triggered every !Beats. The setReset: is what fully enables the timing trigger. Without the setReset: function, the performer would have to hold the button over the next beat in order to activate the trigger. No audio example provided, but Kyma Sounds are included in software (Appendix B).

Control LoopStart/LoopEnd on Button Press/Release

The Wacom may be used to select portions of an audio buffer. For example, by clicking and dragging across the X-axis (TimeIndex parameter), the performer may control the sample selection of an audio file (Figure 3-16).

There are several functions related to this performance control, as shown with Capytalk 3-17 (LoopStart), Capytalk 3-18 (LoopLength), and Capytalk 3-19 (LoopEnd). Clicking !PenButton1 starts the sample selection, silently updating its value as !PenX is dragged across the tablet. Upon !PenButton1 release, the selection is created and will immediately begin looping the selection. Since !PenButton1 controls both selection and sample playback, a short 2 ms delay is added to the playback gate in order to ensure that LoopStart, LoopLength, and LoopEnd values are set before playback. Without the delay, there is a possibility the Gate will be set to 0,

[6] Ableton, https://www.ableton.com/en/manual/launching-clips/ (accessed January 8, 2018).

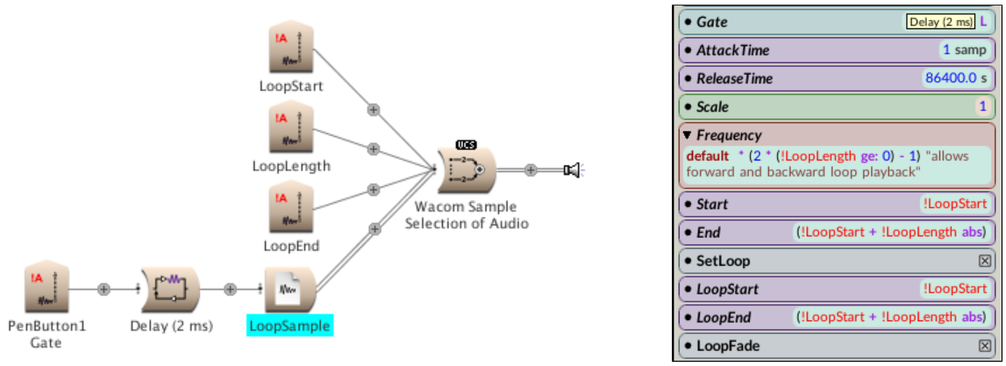


Figure 3-16: Wacom tablet used for selecting loop markers of an audio sample

which will kill the loop feature. The Sound integrates a variable called LoopLength in its Frequency parameter, which determines the function of frequency playback. The frequency of the playback will either be 1 or -1 (forward or reverse) based upon the positive/negative value of LoopLength. Audio 3-17 sounds the feature in action on the Wacom tablet, sampling Dennis Coffey's *Scorpio*.[7]

```
[Move LoopStart to !PenX Location on Button Press]
| start |
start := EventVariable new.
start <+ (!PenButton1 sampleAndHold:  !PenX),
((!PenButton1 -1) abs) sampleAndHold:  start.
```
(Capytalk 3-17)

```
[LoopLength]
!LoopEnd - !LoopStart
```
(Capytalk 3-18)

```
[Move LoopEnd to !PenX Location on Button Release]
((!PenButton1 - 1) abs) sampleAndHold:  !PenX
```
(Capytalk 3-19)

Audio 3-17: Wacom tablet controlling sample selection of the first 16 bars of Dennis Coffey's *Scorpio*.

[7]Dennis Coffey and the Detroit Guitar Band, *Scorpio*, Evolution, Sussex SXBS 7004, 1971.

Speed, Velocity, Acceleration

Calculating Speed, Velocity, and Acceleration are useful for added performance controls. Speed is the rate at which a movement covers distance, and remains positive since it is a scalar value. Velocity includes direction (negative or positive), and the vector depicts the rate at which an object changes position. Acceleration is the rate at which a movement changes velocity. Capytalk Expressions for Speed (Capytalk 3-20), Velocity (Capytalk 3-21), and Acceleration (Capytalk 3-22) are shown below. For normalized mapping output, clipToAbs1 keeps Velocity and Acceleration output to between -1 and 1. clipToAbs1 can be ignored otherwise.

```
[Speed]          (!PenX derivative smooth: 250 ms) abs
```
(Capytalk 3-20)

```
[Velocity]        !PenX derivative smoothed clipToAbs1
```
(Capytalk 3-21)

```
[Acceleration]    !PenX derivative smoothed derivative
smoothed clipToAbs1
```
(Capytalk 3-22)

In conjunction with logic and controller paradigms, Speed, Velocity, and Acceleration values serve performance movement mappings. Two examples are outlined below.

Speed Threshold Trigger

By using a threshold to gate the detection of pen speed, we can turn the continuous data stream into a trigger (Audio 3-18). Capytalk 3-23 depicts a speed threshold trigger, where the user sets !Threshold to match the desired amount of speed before triggering a new event. The Capytalk expression 'hasChangedInLast' acts as a timing threshold that reduces unwanted triggers from signal jitter.

```
(!PenX smoothed derivative abs gt: !Threshold)
hasChangedInLast: !Dur s
```
(Capytalk 3-23)

Audio 3-18: Speed of !PenX on Wacom tablet triggers next sample at random. The trigger is based upon a threshold and timing reset (Capytalk 3-23). !PenY controls continuous pitch bend.

Velocity Ignores Pen Jumps

Since data on the Wacom tablet is transmitted when the pen is in contact with the surface, a common performance behavior on the Wacom tablet includes lifting and moving the pen to a new XY position while off the surface of the tablet. In order to connect performer movements with an input that transmits only while on the surface, one may desire to ignore jumps in fader position values (as !PenDown would only emit continuous data for !PenX and !PenY). Capytalk 3-24 outlines how Velocity may be calculated so only continuous data is tracked while ignoring jumps of the pen to new areas of the tablet. Audio 3-19 sounds the control.

Audio 3-19: Velocity of !PenX on Wacom tablet controlling frequency ratio of eight copies of SampleCloud (granular synthesis). Each sound particle is spread across a two-octave range. !PenX is mapped onto TimeIndex of the audio so movement across X-axis sounds like an arpeggiated strum of the voice.

```
| prev change |
prev := EventVariable new.
change := EventVariable new.
((change <+ ((!PenX - prev) abs)), (prev <+ !PenX),
(((change le:  !DistThreshold) * (change ge:  0.003))
setReset:  (change gt:  !DistThreshold)) * ((change
gt:  !DistThreshold)
  true:  0
  false:  ((!PenX smooth:  200 ms) derivative smooth:
200 ms) clipToAbs1) ).
```

(Capytalk 3-24)

XY Spectral Filter

The Wacom tablet offers an XY space for the exploration of sound space, and audio files map well onto the 2-dimensional surface. While previous audio examples throughout Chapter 3 utilize the X-axis to control audio time, the Y-axis contains many different mapping domain choices. One sonically rich domain to map the Y-axis onto is the spectral domain. Using spectral analysis, an audio file is broken down into spectral tracks containing frequency and amplitude information (Figure 3-17). Spectral analyses typically display time in the X-axis and frequency in the Y-axis. Thus, using a literal map of XY space, the X-axis on the Wacom tablet scrubs through time space, and the Y-axis on the Wacom tablet moves through frequency space.

One way to imagine the traversal of Y-space of the frequency domain is to imagine the Wacom pen as selecting spectra only with its localized position, such that !PenY serves as a spectral bandpass filter. Wherever the pen is located along the Y-axis, the subsequent spectral track is isolated (e.g., 14th, 20th, etc.) and synthesized with a waveform oscillator. In Audio 3-20, !PenY selects single partials and synthesizes the spectral track using a simple sine waveform.

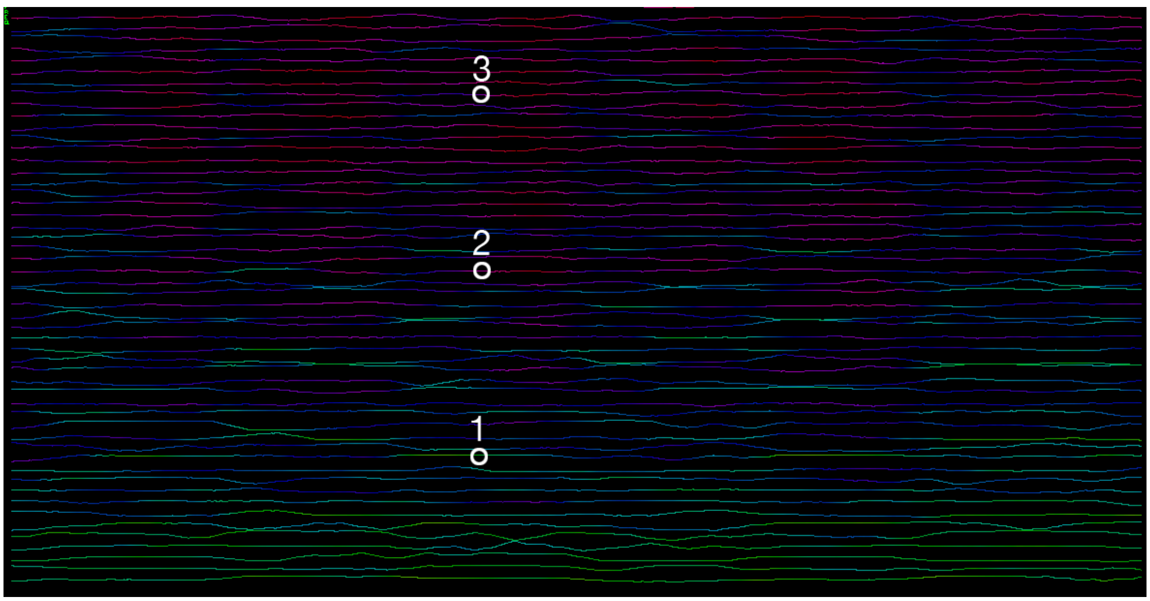


Figure 3-17: Spectral analysis of an audio file depicting bands or tracks containing frequency and amplitude information. Point 1 represents the 13th spectral track at 1058.1 Hz with -29.86 dB. Point 2 represents the 30th track at 2494.2 Hz with -76.08 dB, and point 3 highlights the 46th track at 3867.5 Hz with -70.39 dB.

Audio 3-20: Wacom tablet controlling selection of spectral track using !PenY. Playback is looped.

Another way to imagine the traversal of Y-space of the frequency domain is with playing back all spectra above or below the Wacom pen's location. This method converts !PenY into a low or high-pass spectral filter. Audio 3-21 filters spectra using the Y-axis; here, the Y-axis increases the number of spectral tracks that are played back with the increase of !PenY. Instead of widening the frequency range as with a high-pass filter, the spectral filter harmonically widens the partial range, with the addition/subtraction of harmonic partials. !PenY movement contains scalar additions of partials from the sound; the result sounding like a glockenspiel with its bars finely tuned to the sound's spectrum (and including the specific partial amplitude).

Audio 3-21: Wacom tablet controlling widening of spectral tracks using !PenY. !PenX controls time of the audio file.

Using XY space to traverse through spectral space with the Wacom tablet converts the spatial domain into the spectral. While not the only method for moving through a sound spectrum, the XY spectral filter charts a harmonically rich space for exploring sound.

3.6.2 Gametrak Prototypes

Figure 3-18: Gametrak video game console

The Gametrak (Figure 3-18) contains two three-axis faders with high resolution in the Z-domain. Gametrak is a non-traditional interface, which others have used to build unique instruments (Freed et al. 2009). Additionally, Distance-X in this dissertation utilizes a hacked Gametrak and a Nintendo Wiimote for its design (Chapter 6). While many of the Gametrak prototypes were written with Distance-X in mind, the focus on three-axis fader mappings serve a more general toolkit (Figure 3-19). As will be outlined, three-axis faders afford different expressive movements than either the Wacom or Wiimote.

The Gametrak embeds physical space into a vector, and the Z-axis of its fader affords the performer large physical arm space—the Z-axis fader stretches to roughly 6' of plastic wire—

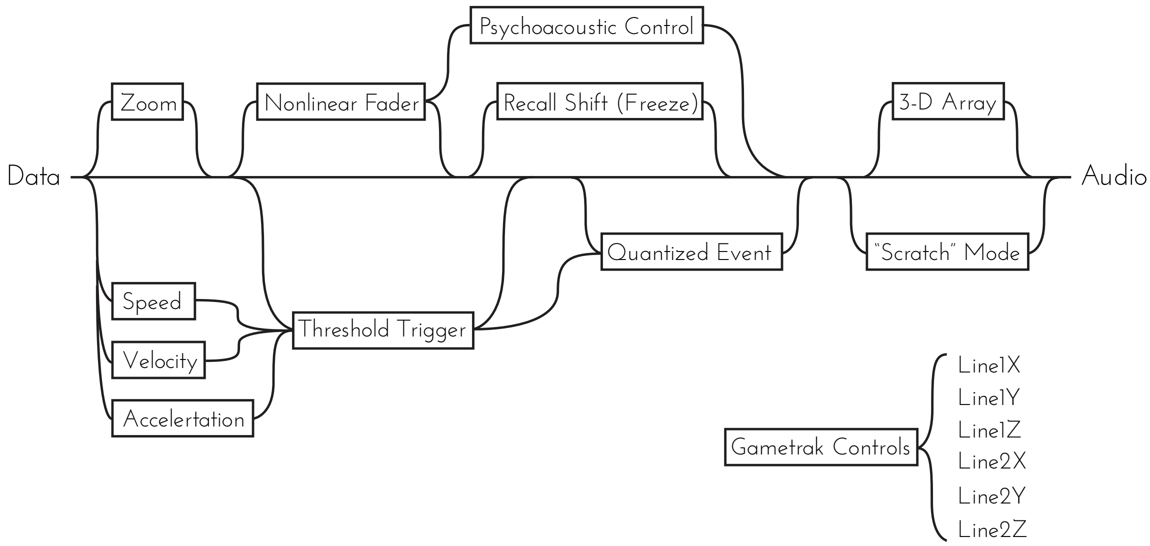


Figure 3-19: Modular overview of basic Gametrak feature prototypes

which extends the performer's parametric space to include the full range of the arms in relation to the interface. Many of the prototypes for Gametrak take advantage of this feature, as many other input devices do not transmit data reflecting such large physical distances.

Spatialization

By interdependently controlling a low-pass filter, wet and dry sends to a reverb, amplitude, and pan, sounds may be statically positioned or moved through an acoustic space (examples provided in Section 3.6.1). By adding a third dimension to the controller surface, the performer gains control over the Z-dimension of a sound in a space, rather than relying on automation to create depth. Thus, the performer may physically move a sound forward/backward in space, and amplitude may be controlled independently.

One example of this effect implements an inverse mapping of arm distance to sound source (Audio 3-22). The closer the fader is to the interface, the further away the sound source location (i.e., less presence of direct sound with an increase in the amount of reverberation or wet signal). Gametrak X pans the sound signal across the stereo field, and Gametrak Y controls angle in front of and above the listener.

Typically, this effect is used post-fader, meaning that as input decreases in volume, so too does the feed to the reverb signal. Higher frequencies roll off when sounds are further away in space, and this is also true here. As the arm spreads out, or away from the interface, sounds become drier and brighter. Higher frequencies roll off as the fader returns back to the resting position (closer to the Gametrak).

Audio 3-22: Spatialization of sound source controlled by a 3D fader (Gametrak)

Scratch Mode

Inspired by “scratch” mode from version 1 of The Hands by Michel Waisvisz (Waisvisz 1987), where Waisvisz used the mapping of hand distance to note events and amplitude, I mapped a similar mode on the Gametrak (Audio 3-23). With The Hands, each data control update (new sensor reading of distance) creates a copy of the MIDI note-on message with the current pitch and respective velocity at that distance (Torre et al. 2016). The mapping of amplitude to hand distance also ties physical hand distance to perceived loudness. The further the hands are expanded, the louder a sound becomes. I leveraged my version of “scratch” mode as a platform to start from as I developed mappings on Distance-X (Chapter 6).

Audio 3-23: A recreated version of Waisvisz’s “scratch” mode played through Z-axis of the Gametrak.

Filtered Noise

The Z-axis of the Gametrak controls amplitude gains and a frequency filter on a fractal noise generator (Scholda and Vogel 2016). All controls are non-linearly mapped to simulate loudness curves and logarithmic frequency space. An additional control mixes in octaves of noise generators to further increase brightness on louder sounds, LevelOctave(n) = Persistance^{n}, before normalizing the output. See Section 3.3 for audio examples of non-linear fractal noise.

Freeze Effect with Gated Threshold

Similar to controls discussed in Recall Shifting (Section 3.2), the Freeze effect uses a short delay and gated switch to hold and replay moments of the past. The maximum distance of one's outstretched arms (Z-axis), and the stoppage of physical arm movement are interesting areas of musical rest. By feeding an audio input to a very short delay (i.e., 256 to 1024 samples), we may cut the dry signal and delay input while increasing delay feedback to 100%, triggered at moments of extreme distance. In short, we freeze the last N-samples of the delay during moments of physical rest when the arms are outstretched. Because the delay is short (no more than 23.1 ms or 1024 samples) the sound blends into a single sonic texture, a frozen moment. We may additionally spectrally analyze the signal before the delay and re-synthesize the analysis signal after the delay, so that the texture sounds less like a stutter (beat repeat effect) and more like a single sonic texture.

Capytalk 3-25 and Capytalk 3-26 display two triggers for Gametrak that cause the Freeze Effect, each of which simultaneously cut delay input, cut dry signal, increase wet signal and increase feedback to 100%. Audio 3-24 uses the Z-maximum threshold to trigger the Freeze Effect, that is, when the performer's arms are completely outstretched.

```
!OSC_gtz gt:  0.96
```
(Capytalk 3-25)

```
!OSC_gtz_accel lt:  2
```
(Capytalk 3-26)

Audio 3-24: Freeze Effect triggered by maximum distance between hands on the Z-axis of Gametrak on the DMI, Distance-X.

Multidimensional Arrays

A 3D fader transmits a 3D vector (x,y,z) within a limited range at control rate. When viewed as a measure of length, the three-dimensional vector may be utilized as an index pointer to a three-dimensional array (Figure 3-20).

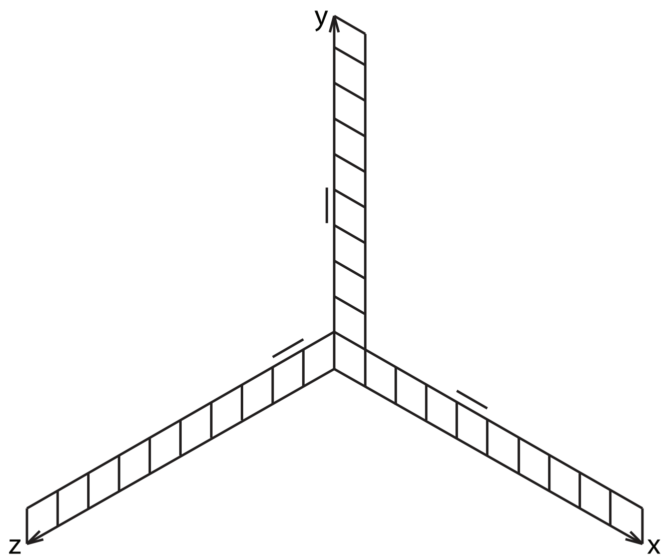


Figure 3-20: 3D fader serving as index pointer to a three-dimensional array with index values X=4, Y=4, and Z=1

By traversing a multidimensional array in physical space, a 3D fader selects multiple values at once. By assigning array values to consist of a single musical domain like pitch, then the 3D fader may select/play three pitches at once, or sound a three-part harmony. Audio 3-25 demonstrates how one fader of the Gametrak traverses pitch space in this way.

Audio 3-25: 3D fader of Gametrak selects pitches for three voices from a multi-dimensional array.

3.6.3 Nintendo Wiimote Prototypes

The Nintendo Wiimote is a wireless video game controller that offers eleven buttons, an accelerometer, gyroscope (with Motion Plus), and an infrared camera (Figure 3-21). The controller communicates via Bluetooth, so that the controller sends data wirelessly into the host computer.

Figure 3-21: Nintendo Wiimote

Coupled Parametric Space

Accelerometer data of the Wiimote enables a performer to control multiple values associated with movement simultaneously. Adjustments in any one of the domains of Pitch (up/down), Roll (twist left/right), or Yaw (side-to-side), typically result in changes to the other two, however slight. The coupling of sensors values fits well in the musical context of interdependent parameters. For example, a increase in volume by a trombonist results in a brighter tone, that is, amplitude is coupled with timbre.

By mapping the three values of the Wii accelerometer to different sonic parameters, the resultant sound contains interdependent relationships, with the performer responsible for commanding these sonic relationships in performance. For example, mapping !WiiRoll as TimeIndex, !WiiPitch as Volume, and !WiiYaw as polyphonic VoiceNumber builds frequency, amplitude, and timbre into a sonic entity controlled by movements of the performer's hand, wrist, and arm. Audio 3-26 demonstrates this interdependent parametric mapping.

Audio 3-26: Interdependent mapping (time index, gain, polyphony, and harmonic resonance) using pitch, roll, and yaw of the accelerometer and gyroscope of Nintendo's Wiimote.

Multichannel Spatialization Using Velocity

Since the establishment of multichannel audio, composers and artists have looked at controlling the location of sounds in space. Pierre Henry developed the *pupitre d'espace* for the dissemination of sounds via induction coils, and Karlheiz Stockhausen used a rotating amplifier to distribute sounds for the performance of *Gesang der Jünglinge* (Chadabe 1997). In Rauschenberg's *Open Score* (1966), performers volleyed sounds in space by using FM radio signals emitted from transmitters set in tennis rackets (Rauschenberg 2007).

By mapping Wiimote velocity and accelerometer data onto sounded objects, the controller can also *strike* sounds between performers inside a space. *Sound Pong* (2011) is a real-time performance composition written in Kyma and Max/MSP for four Wiimotes to spatialize sound objects (Video 3-1).

> Video 3-1: *Sound Pong* (2011) by Jon Bellona and Jeremy Schropp, for Oregon Electronic Device Orchestra (OEDO), performed by OEDO at the University of Oregon, February 27, 2011.

As part of *Sound Pong*, the author developed a modular Wiimote Max abstraction to ease compositional work flow using Wiimotes inside Max/MSP (Figure 3-22). The abstraction is free and available online (https://cycling74.com/toolbox/wii-controllers/) and part of Appendix B.

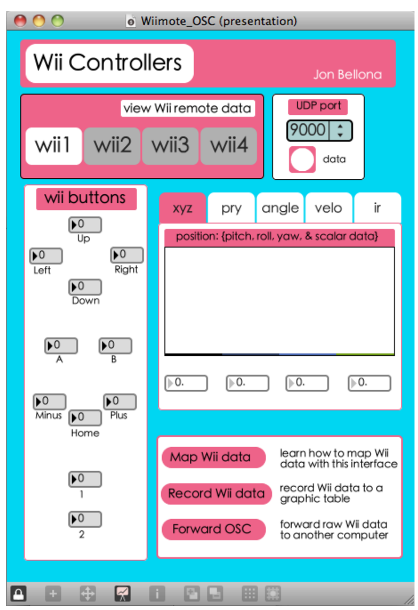


Figure 3-22: Wiimote Max abstraction

3.6.4 Microsoft Kinect

The Microsoft Kinect is a 3D video camera that identifies and groups objects in three-dimensional space (Figure 3-23). The hardware requires drivers to access the 3D video data (thousands of IR points in space), as well as additional libraries that provide access to information about a human body in space (fifteen 3D vectors representing body joints, drawn as a skeleton). From 2011–13, the author wrote and published two different open-source applications for working with the Microsoft Kinect. The first application, *Kinect-Via-*, is a Max/MSP interface series for receiving and sending user tracking data via Open Sound Control (OSC) messages from four different OpenNI applications, namely OSCeleton, Synapse, Processing's simple-openni library, and Delicode's NIMate (Bellona 2012a,b). The second application, *simpleKinect*, transmits data from the Microsoft Kinect (model 1414) to any OSC-enabled application (Bellona 2012c). I composed a solo work, *Casting* (2013) for *simpleKinect* and Kyma (Video 3-2).

Figure 3-23: Microsoft Kinect (v.1.0)

simpleKinect has two software versions. The first version is a bundled application built from Processing for Mac OSX < 10.8. The latest version is a Processing sketch that works for Mac OSX 10.8+. Once Kinect drivers have been installed on the host computer, *simpleKinect* may be downloaded and opened. A single user skeleton calibrates automatically, and sends up to fifteen different joints as OSC messages. Torso information of all users is sent, regardless of skeleton calibration.

simpleKinect features include:

- Auto-calibration; where a user is immediately tracked upon entering the Kinect camera's field of vision.
- Update OSC output IP and Port in real time.
- Send CoM (Center of Mass) coordinate of all users inside the space, regardless of skeleton calibration.
- Toggle Center of Mass (torso joint) on/off for all users.

- Toggle sending skeleton data (single user), on a joint-by-joint basis, as specified by the user.
- Individually determine the OSC output url for any joint.
- Individually select between three joint modes (world, screen, and body) for sending data.
- Save/load application settings
- Send distances between various joints (sent in millimeters).[8]
- Manually switch between users for skeleton tracking.

Video 3-2: *Casting* (2013) for Microsoft Kinect, *simpleKinect*, and Kyma

3.6.5 Data Communication Max Packages

Composers and performers working with DMIs often require some type of custom software interface for working with their specific input controller/sensor. This could be as high-level as the integration of MIDI inputs within a digital audio workstation (e.g., Reaper, Logic Pro, ProTools), or as low-level as binaries executed via a utility like Terminal. Throughout the last seven years working with DMIs, I have crafted many Max abstractions and packages tailored toward DMI contexts. While I previously discussed a data modification Max package and two controller applications, this section describes two Max packages dealing with data communication: *data.** and *KorgNano*.

data.* Max Package

*data.** is a basic Max package for working with data communication (Appendix B). Most of the *data.** objects extend native Max objects in order to add functionality for addressing the author's data communication work flow on DMIs.

data.serial

data.serial extends the Max *serial* object for specifically querying data from Arduino sensors at control rate. Max sends a single 'r' character every N-milliseconds, which adds an additional check between the *analogRead()* of an Arduino and its print function. Without checks

[8]The software sends distance values between left hand and right hand, which became a design resource for Distance-X (Chapter 6).

between Arduino and the serial port running inside Max, the system may return unwanted data or incorrect chunks, sometimes leading to Max/MSP crashing. *data.serial* helps resolve communication issues from input controllers for more stable performance. Example Arduino code that uses *data.serial* is included within the package (Appendix B).

data.midiinfo

data.midiinfo extends the Max *midiinfo* object by appending two additional arguments. The first takes input or output as its argument and switches the *midiinfo* umenu to be a MIDI input or output. A second optional argument is the name of a send (string literal) that automatically sends *midiinfo* selections out its own send object. The named send enables the quick creation of midiport information that can be sent to all midi objects throughout the DMI project.

data.keys

data.keys bundles all 'qwerty' keys into various 0–9 output combinations, and the object includes a CAPS lock piano keyboard based off the CAPS lock keyboard in Logic Pro. The object was created for recalling preset assignments as well as for incorporating a mini keyboard into small performance and sound design projects.

data.oscout and *data.oscout.master*

data.oscout extends the *udpsend* object with url, port, and ip arguments. Much of my input data in Max/MSP is eventually sent out to synthesis software, like Kyma, which requires the use of software-software communication using Open Sound Control (OSC) messages. An optional argument names a *receive* object for *data.oscout* to alter the port and ip information of its *udpsend* object. The *data.oscout* object works well with *data.oscout.master*, a bpatcher that quickly sets the port and ip address of all *data.oscout* objects by including a global send to all *data.oscout* instances (off by default). An optional argument names a *forward* object to keep OSC ip/port information localized if desired.

data.scale

data.scale extends the Max *scale* object by dynamically and non-linearly scaling data, including various non-linear functions. The *data.scale* object has previously been released with jpb.mod.*, discussed in Section 3.3.

data.scale.expr

data.scale.expr non-linearly scales data based upon common expressions. Common expressions (read equations) include pitch ratio transposition, linear to log (dB), radians to degrees, and BPM to ms conversion.

data.zoom

data.zoom magnifies a data stream for live performance. This function has been discussed extensively in Section 3.1 and Section 3.6.1.

data.ttout and *data.ttin*

data.ttout and *data.ttin* enable dynamic sends within Max/MSP in order to cut down on repetitive tasks. *data.ttout* extends the Max *forward* object; each instance of *data.ttout* populates a umenu that is comprised of the collective instances of all *data.ttout* send names. *data.ttin* is a data listener that contains a populated umenu of these send names, which is attached to a *receive* object. *data.ttin* outputs appropriate data of its *data.ttout* menu selection. The menu of named send objects allows one to dynamically select whichever control one desires to receive data from. A user does not need to remember string literal send names.

For example, there are 151 buttons, faders, and knobs in the four scenes of the Korg nanoKontrol controller. Rather than having to create send/receives each time or recall the string literal send name, the user may select the input control name the user wants to receive data from (e.g., Scene1_Channel6_Fader). The input control name directly relates to one's understanding of the device (and mapping need) in the moment. The *data.ttout* and *data.ttin* objects help foster "just-in-time" learning (Norman 2011, 264). *data.ttin* and *data.ttout* have been implemented and included within the Max Package, *KorgNano*, described next.

KorgNano Max Package

KorgNano is a software representation of Korg's nanoKontrol inside Max/MSP (Bellona 2015c). The package connects the nanoKontrol hardware to Max and automatically ports the data to *korgnano.inputmenu* objects (a specially-named *data.ttin* object). Figure 3-24 shows how *data.ttin* is used within the author's *KorgNano* Max package.

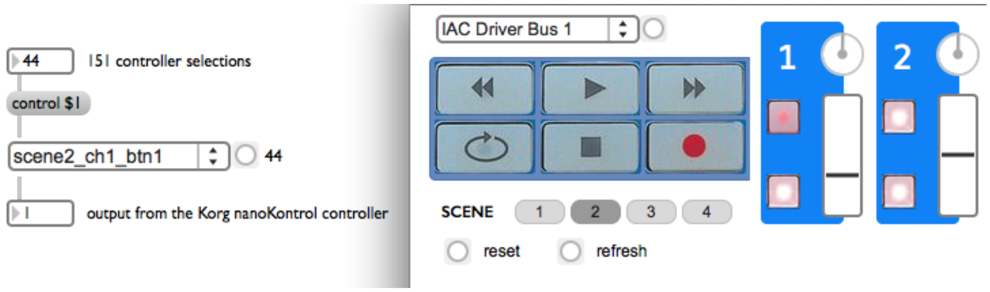


Figure 3-24: *KorgNano* Max package utilizing *data.ttin* and *data.ttout* objects

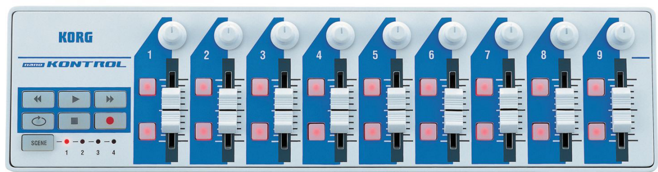


Figure 3-25: Korg nanoKontrol USB controller (v.1.0)

For the *KorgNano* Max Package, *data.ttin* was renamed to *korgnano.inputmenu* to make the bpatcher object easier to use with this Max Package. The object makes the *data.ttout* list static since the order and number of controllers remains fixed for the USB device. One may think of *korgnano.inputmenu* as a 'receive' object specifically designed for the nanoKontrol. Just like *data.ttin* was used for *korgnano*, a *data.ttin* object may be renamed and placed inside a bpatcher like *korgnano.inputmenu* in order to create a receive object framework for any device or project.

In Closing

Expression Toolkit strives to broadly consider how sound and performer interact with different interfaces and control paradigms. The toolkit encapsulates a myriad of software, theories, and processes in order to aid the DMI practitioner. The following chapter, Composition and Performance Practice on Alternate Controllers, builds from the concepts and elements contained in Paradigms of Control and Expression Toolkit chapters to more holistically address the alternate controller DMI inside a musical practice. The chapter concentrates on the relationships between composer/performer/instrument, providing case studies, working models, and a performance-based value system.

Chapter 4

Composition and Performance Practice on Alternate Controllers

> I don't like little pitch wheels that can make a huge orchestral glissando. I want to bring body information to musical systems.
>
> Michel Waisvisz (Lehrman 1986, 22)

Live performance in computer music has been around for several decades, and the practice of performing on DMIs has been discussed by many with wide-ranging topics from sustainability (Baguyos 2014), human effort and intention (Ryan 1991), laptop and group ensembles (Nick Collins 2003; Knotts et al. 2014), assisted performance (Baguyos 2014), degree of human control (Birnbaum et al. 2005; Rolnick et al. 1992), network music (Tanaka 2009), notation (Baguyos 2014), video-game play (Turowski 2016), audiovisual context (Ciciliani 2014), acoustics (Kimura 1995), interactive performance systems (Drummond 2009; Garnett 2001) and even extra-musical considerations (Kimura 1995). Several performance typologies have become established over the past few decades, including: performer-engineer (Baguyos 2014), laptop or group ensembles (Knotts et al. 2014), live with fixed media (Kimura 1995), interactive (Garnett 2001), improvisational (Krefeld et al. 1990), and composer-performer (Dobrian et al. 2006). These varied performance types address performance contexts and may overlap in practice. In fact, the case studies presented in this chapter for Wacom tablet and Kyma touch upon several of these performance types. Still, the broad approaches toward a DMI performance practice are evolving and for a composer-performer, these changes may be experienced over the life of a digital technology, the life of an instrument, or the life of one's career.

With alternate controller DMIs, composers often perform their own works (Drummond 2009; Jordà 2017), whether or not they have technical assistance (as with Michel Waisvisz and Maurits Rubinstein (Bellona 2017)) or perform in a group ensemble (The Hub, Sensorband). In addition, composers commonly develop their own instruments (Jordà 2017; Tanaka 2009), which extends a composition practice to include working with hardware sensors, software mappings, and instrument design. This holistic approach to DMI composition and performance practice requires a unique understanding of the instrumental interface that often moves beyond the musical (Magnusson 2009). The brief history of composer-performers on DMIs invites questions about pedagogy, artistic development, and the customary practices of composer as performer that blur the boundaries between traditional composition and performance practices. For example, it is standard practice for acoustic composers to write for varied instruments and contexts, but not to build the instrument for the performer. Likewise, it is standard practice for acoustic performers to dedicate their careers to a single or small set of instruments (and he/she may even commit to a single genre or style of playing), but not necessarily to compose for, nor to build their instruments. Looking specifically at the composer-performer-instrument relationship on alternate controller DMIs, the lines between these two historical roles fade, leaving two basic models of a DMI composition and performance practice—the **singular model** and the **modular model**.

The **singular model** originates from acoustic performance practices, where a trained musician typically trains on and performs with a single instrument throughout one's career. For example, a violinist studies the violin and the instrument's relation to musical activity through active rehearsal and performance. While one masters one's instrument, one may learn extended techniques, amplify the instrument with electronics, or augment the instrument using digital technology (e.g., K-Bow). Regardless of these performative additions and sonic transformations, the violinist remains a violinist. The performer remains coupled to the violin as physical object. In the DMI singular model, a composer-performer remains dedicated to a single instrument for an extended period of time (e.g., Laetitia Sonami's Lady's Glove, Atau Tanaka's BioMuse, Marco Donnarumma's Xth Sense). This is not to suggest the instrument couldn't be augmented, altered, or adapted to fit new composition and performance contexts.

The **modular model** stems from acoustic composition practices, where a composer writes for many different instruments and ensembles. This may include writing short or extended works like études or symphonies, writing for solo or group instrumentation, and even arranging pre-existing music. The modular practice for a DMI composer-performer includes composing for different DMIs (which may include the building of an instrumental interface and software) and performing on these DMIs as a standard practice, instead of remaining coupled to a single instrument.

These two approaches to DMI composition and performance practice—the singular model and the modular model—lead out in different directions, and may be understood through the creative output of two composer-performers: Michel Waisvisz and Jeffrey Stolet. Michel Waisvisz is known for his development of the Crackle Box and The Hands (and at times his lesser known instrument, Tape Puller) (Otto 2008), and Waisvisz wrote for and performed on various versions of The Hands for 20+ years until his untimely death in 2008. In one sense, Waisvisz's approach toward a single instrument parallels acoustic musicianship. Waisivisz performed, tweaked, built, revamped, and stuck with the same instrument over the course of his career. Even though there were three hardware versions of The Hands (Torre et al. 2016), Waisvisz remain dedicated to composing and performing on this instrument.

Conversely, Jeffrey Stolet studies, composes, and performs on different DMIs for almost every new work. Instead of building on and from a single DMI, Stolet treats the instrument as part of the compositional process. He studies the modularity of sensor components and how these various inputs serve different artistic aims. For example, *Tokyo Lick* (2001) for interactive performance environment, Yamaha Disklavier, two infrared MIDI controllers, and two MIDI foot pedals explores the infrared sensor and its relationship to notions of hand distance, density, activity, up/down metaphors, and traditional devices of piano performance (Video 4-1) (Stolet 2006).

Video 4-1: Tokyo Lick (2001) by Jeffrey Stolet (Stolet 2007)

The instrument and its input for *Tokyo Lick* are important to the physical realization of the work. It is no accident that the performer stands in relation to the infrared MIDI controllers to express the vertical range of the mapped keys, or actively moves both hands with calculated determination as a complement to piano performance. After *Tokyo Lick* (of which there are several performances), Stolet moved away from composing for infrared technology. Instead, he composed *Light* (2007) for real-time video analysis and two flashlights; *Things I Do With My Fingers* (2007) for two Nintendo Wiimote Controllers; *Lariat Rituals* (2012) for Gametrak; and *Imagined Destinies* (2014) for book and two microphones, among other works. Each of the aforementioned works represents submersion in a digital technology, an instrumental development with the performer, and a compositional idea that works with and from these technological and interpersonal relationships. Collectively, Stolet's works serve as a modular model of DMI composition and performance practice, where a composer-performer works with different DMIs over time.

Both composer and performer types have a valid composition and performance practice. One struggles with a singular musical object throughout many musical contexts, and the other struggles with the elements of these musical objects (that is, object typologies and affordances). The two basic models of composition and performance practice on alternate controllers do not represent isolated camps of practitioners or devotees, but rather the models invite different questions and explorations into musical expression.

In my own practice, I spent a number of years working from a modular model in alternate controller composition, where each year I would compose for and perform on a different DMI (see Appendix A). I spent another period concerned with performance practice issues, and I underwent a period of composing and performing a selection of works for Kyma and Wacom tablet, including performing pieces by other composers. Three of these works are discussed below. These works-as-case-studies explore various questions regarding the sustainability, retransmission, aesthetics, and the musicianship of alternate controller DMIs. The works additionally outline the active consideration of physical movement as a creative force within an alternate controller performance practice.

4.1 Case Study: *Smooch* (2014) for Wacom Tablet and Kyma

Aim: Composing repertoire for the development of a DMI composition/performance practice

Digital Musical Instrument: Wacom tablet and Kyma

This case study demonstrates composing repertoire for a single DMI similar to how we compose for acoustic instruments. Writing for new electronic instruments isn't new; Varèse and Messiaen incorporated electronic instruments into symphonic works in the 1930s (Holmes 2008, 27). Composing for a particular instrument fosters tradition, culture, and instrumental longevity. Varèse and Messiaen contributed to the Ondes Martenot repertoire, and perhaps, in part, it is through their work that the instrument has become one of the more notable electronic instruments, with now "over 300 composers [contributing] to this repertoire" (ibid., 27).

Repertoire can be a difficult thing to achieve for alternate controller DMIs; the make-up of a DMI may shift over time as the various digital technologies that constitute it change or become outdated. So, how does one create repertoire if one did not build or develop the DMI? After all, DMIs are often the invention of the composer. And what happens if we alter certain defining elements of the DMI? What constitutes repertoire if only part of the instrumental model survives? For the purposes of my musical research, I identify 'repertoire' as music for a particular iteration of an instrumental model, where the instrument's components (input interface, software mappings, and sound synthesis) remain more or less the same.

I composed *Smooch* (2014) as a DMI composition experiment, attempting to create 'repertoire' re-using digital elements that define a DMI (Chapter 1). The underlying Kyma software of *Smooch* is a simple modification of software originally written by Gabriel Montufar for the first movement of his piece, *My Inner Self* (2013), for Wacom tablet and Kyma.[1] *Smooch* maintains almost all of the elements of Gabriel's instrument; I kept the core X/Y mapping of the time/frequency domain on the Wacom tablet (Table 4.1), stripping out only the post-fader aux send audio effects. The rest of the composition process ignores any additional pointers to Gabriel's work, instead using the tablet and its mapping as a point of departure to develop a

[1] I am indebted to Gabriel for sharing his software with me for exploring this specific composition question. Gabriel's *My Inner Self* is available online: https://www.youtube.com/watch?v=vLD9F_ICUcA (accessed April 19, 2018).

new work led by the ear and arm (Video 4-2).

Table 4.1: Main software mappings used in *Smooch* (2014)

Wacom Input	Sound Control	Original Mapping
Pen Down/Up	sound on/off	yes
X position	sample time location	yes
Y position	frequency	yes
Pen Tilt Y	amplitude	no
Pen Button 1	tap delay on/off	yes

Video 4-2: *Smooch* (2014) performed at Dartmouth College, February 10, 2015. The concert featured a new practice of holding the Wacom tablet (see Figure 4-5).

In wanting to make the work accessible to other performers, I developed a graphic score to accompany the work (see Appendix C). Notes that outline physical movement, sonics, and performer expression were placed in correspondence with the action in the score (Figure 4-1). Introductory remarks from the score dictate performance practice values. Some of the values outlined in the score include:

- Never stop moving the pen. Make micro-movements if lingering in a single spot. Micro-movements of the pen will add interest to the sound, otherwise emphasis will be given to sinusoidal oscillators, which decreases musical interest.
- Listen. While there is a choreographic score that accompanies this work, the performance requires one to listen how sound phrases develop that will, in turn, determine the lengths and dynamics of each subsequent phrase.
- The score should be memorized/internalized. The work requires the ear and hands to lead the piece, not the reading of a score. Make the piece your own!

Performance practice values here underline my approach toward DMI performances—the rehearsals, the mental state, and the physical tuning of the performer—all of which will be discussed in further detail in Section 4.4: *Performance Practice Values on Alternate Controllers*.

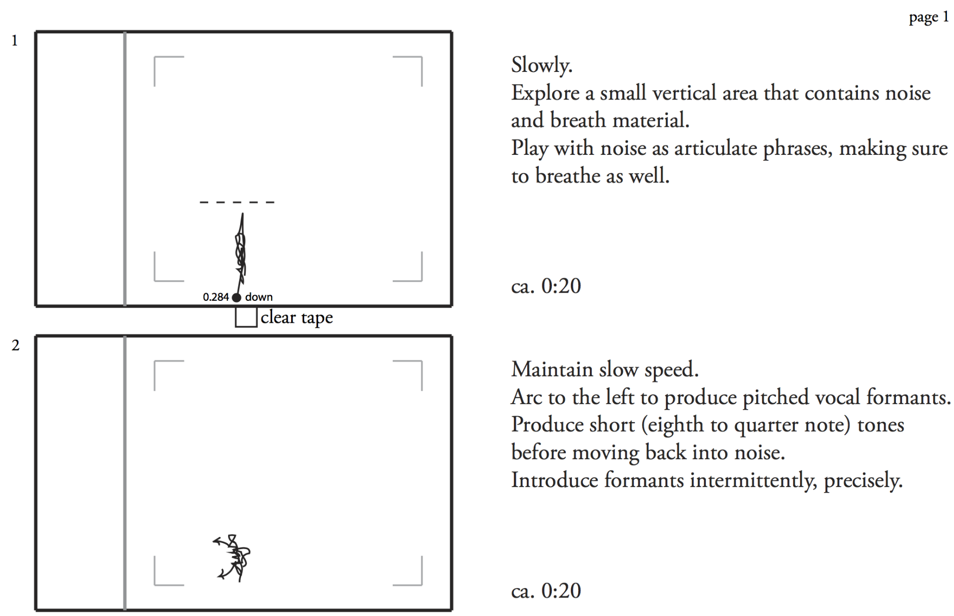


Figure 4-1: Excerpt of score from *Smooch* (2014). Notes aid movement and sound concurrently.

4.2 Case Study: *AUU* (2010) for Wacom/Kyma and *AUU* (2014) for eMersion™/Kyma

Aim: Extending the instrumental paradigm (modularity) of the DMI model

Digital Musical Instrument: Wacom tablet and Kyma (2010); eMersion™ sensing remotes and Kyma (2014)

This case study explores how a DMI work may be revamped for a new instrumental configuration. In acoustic composition, it is common to arrange an existing work for a new ensemble (e.g., Maurice Ravel's orchestration of Modest Mussorgsky's *Pictures at an Exhibition*). In alternate controller composition, the DMI's modular construction—interface, software mapping, and sound synthesis (Miranda and Wanderley 2006; Tanaka 2010)—make reworking a musical piece a different sort of task. Indeed, DMIs rely on technology that may go obsolete, and works that rely on digtial technology run into challenges when performed years later. In order to combat these challenge some freeze the technology alongside the work (e.g., Jeffrey

Stolet's *Light* (2007) performances run software from an older Mac laptop with a specific OS); some port the work to an updated technology (e.g., Philippe Manoury's *Pluton* from Max/MSP to Pure Data[2] or Pierre Boulez's *Répons* from 4X to laptop (IRCAM 2007));[3] and some develop open-source systems to handle the repetition of effects and software port of hardware rack units (e.g., David Wetzel's Interactive Event Manager (IEM) (Wetzel 2006)). One concern for any new DMI arrangement is how the interchange of the DMI's components affect the musical performance.

Beyond technological obsolescence, reworking a DMI piece may involve changes to the sensor interface (the instrumental object) or software mapping (instrumental behavior). Acoustic orchestration practice builds from an existing musical history with familiar sounds and sound qualities. However, a change in DMI design may disrupt a composition practice. To ensure congruence, the task of reworking a DMI or piece requires listening, incremental tests, and additional rehearsal time with each new design alteration. The DMI modular design implores a composition-performance practice question: how does the musical performance *feel* if we alter one of these components while attempting to maintain the original sound? In 2014, I had the opportunity to answer this question. I was asked to perform in the 2014 Margaret Guthman Musical Instrument Competition,[4] and I reset *AUU (And Uh Um)* (2010), substituting the entire input interface while attempting to keep the performance and sounds intact. I altered the input interface for *AUU* from Wacom tablet to eMersion™ wireless sensors (see Figure 4-2).[5]

Video 4-3: *AUU* (2010) performance at Dartmouth College, February 10, 2015

[2]Miller Puckette, "Interactive Software Design for Pluton," (lecture, University of Virginia, Charlottesville, VA, October 23, 2016). http://music.virginia.edu/technosonics-transmission (accessed October 21, 2016)

[3]Christian Hertzog, "Review: Steven Schick dazzles in Boulez's 'Répons'," *San Diego Union Tribune*, February 2, 2017. http://www.sandiegouniontribune.com/entertainment/classical-music/sd-me-review-reed-20170202-story.html (accessed December 25, 2017)

[4]Margaret Guthman Musical Instrument Competition maintains its own website with few archives of past competitions, but is available online, https://guthman.gatech.edu (accessed March 3, 2018).

[5]I am indebted to Chet Udell for inviting me to perform as part of his eMersion™ wireless sensing technology finalist showcase at the international competition. http://www.unleashemotion.com (accessed March 3, 2018).

Video 4-4: *AUU* (2010) performed at the 2014 Margaret Guthman Instrument Competition held at Georgia Tech, February 21, 2014. The work was re-set for eMersion™ wireless sensing instead of using Wacom tablet as the performance interface.

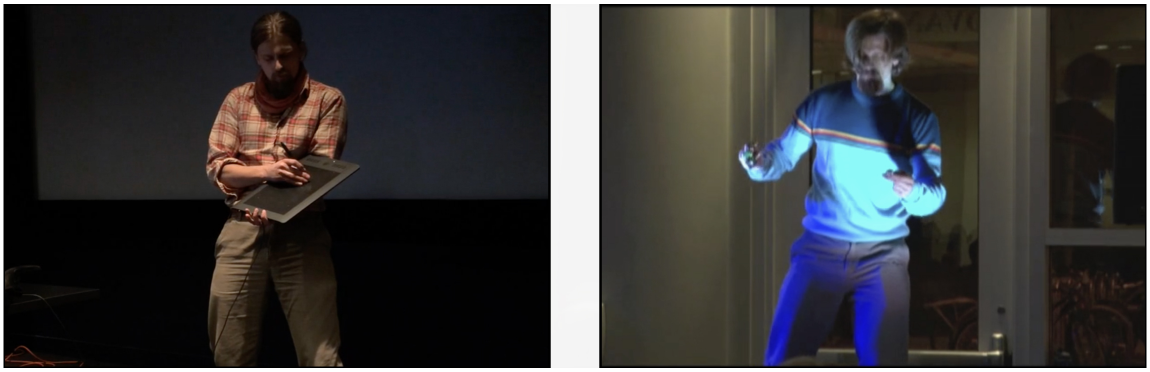


Figure 4-2: (Left) *AUU* for Wacom tablet and Kyma. (Right) *AUU* for eMersion™ sensing and Kyma. Stills are from the same musical time.

The Wacom Pen controls of *AUU* call for three buttons (Pen down, Pen button 1, and Pen button 2), and I had to customize the eMersion™ Accelerate in order to accurately represent controls afforded by the Wacom tablet. The custom button interface and eMersion™ wireless sensing devices are shown in Figure 4-3.

Switching out the input interface opened up an interlocking and cascading set of performance and design challenges. For example, the shift in sensor behavior of the eMersion™ Twist altered the negotiation of performance movement, which impacted scaling ranges of input-to-output mappings, which in turn impacted rehearsals for the physical performance. Switching out the input interface required devoted attention to the physical execution while concurrently listening intently to the resultant sound. The two controllers afford two different types of physical interactions. The Wacom tablet is tactile; eMersion™ is non-tactile. The Wacom provides a clear boundary by which to navigate X/Y space as part of the original mapping; eMersion™ does not. With the eMersion™ remotes, I was forced to *feel* the location of X/Y space through my joints, wrists, and arms. Configuring the eMersion™ technology to behave similarly to the precision of X/Y location on the Wacom required more rehearsal and practice time. Yet, being the composer-performer in both iterations of the work allowed me to lean on muscle memory to navigate the change in instrumental object. The physical memory of one piece carried into the physical learning of the other.

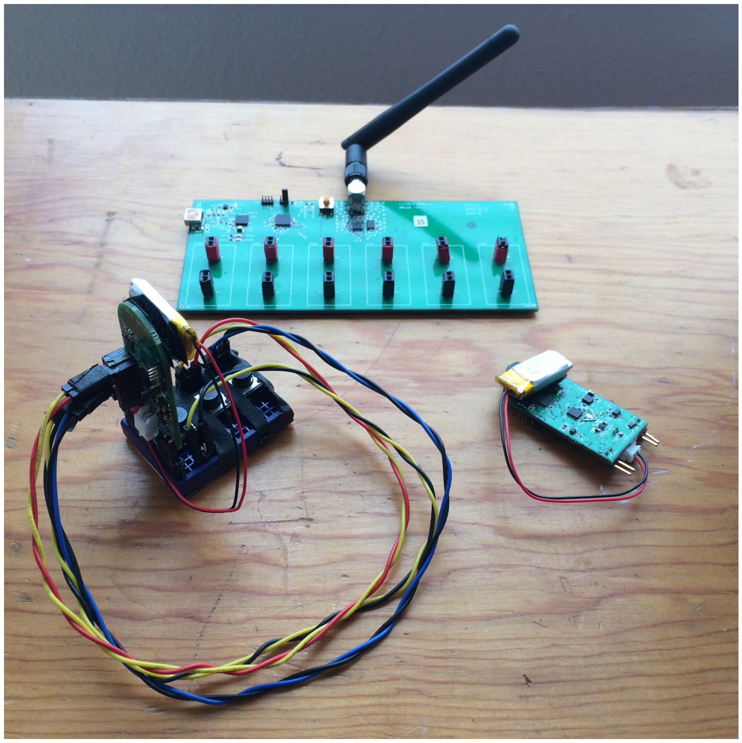


Figure 4-3: eMersion™ Accelerate and Twist sensors with Fuse charging hub. Custom buttons attached to Accelerate sensor to simulate controls of Wacom pen. The interface used for *AUU (And Uh Um)* at the 2014 Margaret Guthman Instrument Competition.

4.3 Case Study: *Breeze* (2015) for Wacom Tablet and Kyma

Aim: Performing repertoire on alternate controller DMI solely as the performer

Digital Musical Instrument: Wacom tablet and Kyma

This case study demonstrates an exploration into performing repertoire for a DMI, where the composer and performer are different agents. DMIs have seemingly evolved to blur the boundaries between instrument designer, composer, and performer, where previously these roles have been considered separate (Drummond 2009). The DMI composition practice that encompasses building instruments as part of the work reaches back to Gordon Mumma's *cybersonic* practice, where the creation of electronic circuits was a necessary part of the composing process (Holmes 2002, 228-9).[6] While groups like the HUB wrote compositions executed by group members (C. Brown, Bischoff, and Perkis 1996) and laptop orchestras offer new creative outlets (Knotts and Collins 2014), today, the expanded creative practice of building/composing/performing on alternate controllers remains mostly a solo activity.

Outside the laptop as interface, few composers develop alternate controller DMIs specifically for DMI musicians, although with the growth of computer ensembles, that field is expanding.[7] When involving outside agents like performers, certain questions about communication and instruction arise. What is involved in learning an alternate controller work that was initially written for someone else? What are the additional considerations for performance on an alternate controller when one was not physically present throughout the building or composition process? While these are perhaps less critical questions for performers of traditional acoustic instruments, they demonstrate the insular nature of most DMI composition and performance practices. There is a closed door to outside performers, seemingly through the intimate and mediated experience that unfolds during the DMI creative process.

Very often, alternate controller DMI works do not include published scores or notes.[8] Perhaps due to the idiosyncratic nature of most alternate controller DMIs, performance documentation of DMI works holds less value or ends up as an afterthought. Works that do not have scores must be learned by watching video, reading program notes, working directly with the composer, and/or creating one's own score/shorthand. Even in the presence of documentation, DMI works contend with software and hardware that contain many technologies and/or sonic outputs (e.g., spatialization, as in Luciano Berio's *Altra voce* (Giomi et al. 2003)).[9]

The challenges of performing alternate controller works underscore a need for human-centered representations that communicate the intricacies of interactive music systems, as

[6] Alvin Lucier also composed music in this way, commenting, "There were no scores to follow; the scores were inherent in the circuitry" (Lucier 1998).

[7] Many performers within laptop ensembles are not musicians of a particular alternate controller, but instead learn a particular interface or instrument for a class or concert. The use of laptop as interface has grown with the expansion of live coding and performance software (e.g., Ableton Live), but that does not guarantee the inclusion of alternate controller inputs.

[8] In a review of alternate controller DMI works given as examples throughout this dissertation, many do not include published scores or notes. It should also be stated that conferences like New Interfaces for Musical Expression (NIME) do not focus on the inclusion of scores or related performance documentation as part of conference proceedings.

[9] Berio's *Altra voce* (1999) is not a DMI composition, but the explicit indications of spatialization help provide a clear example of challenges for scoring electronics for performance.

Spiegel (1992), Birnbaum et al. (2005), and Magnusson (2010b) have attempted to do. Even with instrumental representations, performing another's alternate controller work involves dialogue and collaboration. My desire to perform others alternate controller works led me to reach out to composers of Wacom tablet and Kyma works, including Chi Wang and Olga Oseth at the University of Oregon. Their conscious efforts to provide documentation and notes were invaluable to me as a performer. Still, even with the composer's help, I ended up relying on my own shorthand for realizing their work. Learning their DMI compositions reminded me of David Tudor's diligent preparation of John Cage works, where Tudor created his own nomographs to realize musical material (Kuivila 2001). My shorthand aided the memorization / internalization process, a process integral to the work's realization. For example, since I was without a score for *Breeze* (2015) by Olga Oseth, I created a movement shorthand for Wacom position and direction of phrases within the piece (excerpt of notes shown in Figure 4-4); I annotated her performance video (Video 4-5); and I meticulously rehearsed the movements phrase by phrase in order to execute her work (Video 4-6).

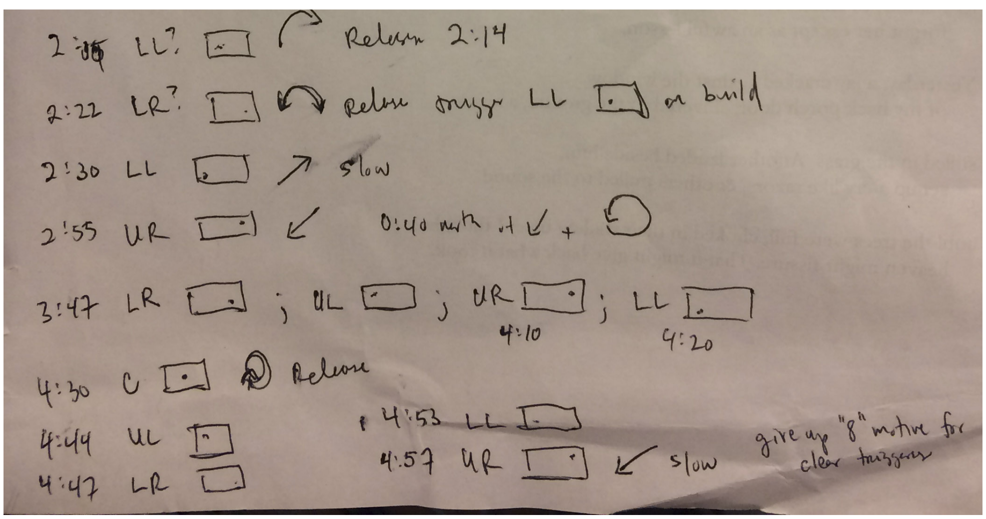


Figure 4-4: Excerpt of author's movement notes for Olga Oseth's *Breeze* (2015). Notes were created to help rehearse and memorize the piece through movement.

Video 4-5: *Breeze* (2015) by Olga Oseth, performed by Olga at the University of Oregon at a Future Music Oregon concert (Oseth 2015).

Video 4-6: *Breeze* (2015) performed by the author at Old Cabell Hall, University of Virginia, May 2, 2016. Olga's original 2015 performance may be viewed on YouTube (ibid.).

Within traditional performance contexts, works require instructions to help articulate desired sounds and/or movements required to execute desired sounds. DMI performances that move beyond the solo composer-performer, especially on alternate controllers demanding refined motor memory, may need to turn to resources beyond scores and notes. Looking to performers of contemporary music (i.e., David Tudor) and alternate controllers (i.e., Michel Waisvisz, Jeffrey Stolet), we may find lessons in approaches to performance. Certainly, in the creation and execution of DMI compositions, I have developed specific performance practice values on alternate controllers.

4.4 Performance Practice Values on Alternate Controllers

A creative DMI practice on alternate controllers remains explicitly tethered to the human performer. This chapter has so far discussed the creative roles within DMI composition and performance practices and pointed out physical approaches. In composing for and performing on alternate controllers, I have developed several performance practice values that underscore the interwoven ties between body and idea (shown below). These values will be discussed in greater detail immediately following, and collectively these values contain ideas central to Physical Composition (Chapter 5).

Performance Practice Values on Alternate Controllers
(under the direction of Physical Composition)

1. Memorize the work to create opportunity
2. Configure the instrument to fit the performance paradigm
3. Add notes (in score or software) to assist with physical expression
4. Review all elements of the performance context
5. Listen intently to develop movement alongside sound activity
6. Move with intent to open up sonic possibility
7. Develop an unfettered belief in the physical self
8. Treat rehearsal as performance
9. Rehearse until sound becomes movement and movement becomes sound
10. Video document the work to assist future performances

1. Memorize the work to create opportunity

Memorization reveals aesthetic possibility and carves space for the performer. Memorizing a work is important to ensembles like Eighth Blackbird, who focus on score memorization in order to open up the stage to presentation possibilities.[10] To internalize the musical actions and physical movements required to play an alternate controller DMI work, a score or movement instructions can be useful (Value 3). Memorization is about "corporeal anticipation," where the performer anticipates her next move such that transitions remain smooth and coherent (Sennett 2008, 175). An instinctive proprioceptive knowledge developed through the memorization process frees up mental space for deep listening of sound, which is crucial for identifying *how* to navigate through physical space effectively (whether the concern is form, phrase, or intonation). Steve Dixon explains these corporeal connections and why they matter:

[10] Corinna da Fonseca-Wollheim, "Concert Choreography: When Musicians Get Up and Move," *New York Times*, July 28, 2017. https://www.nytimes.com/2017/07/28/arts/music/concert-choreography-when-musicians-get-up-and-move.html (accessed July 30, 2017)

> In numerous motion-activating systems developed by or for performers, the body affects a clear cybernetic feedback loop: an arm gesture provides a computational input that is deciphered and reconfigured to trigger an output in another form, such as a music sample or video image. Ostensibly, the body of the performer and the piece of music or video are distinct entities or 'objects,' but within cybernetic understandings they are no longer separated; they are intimately connected within a communication and control system. (Dixon 2007, 147)

Memorization helps remove hesitation and creates space for the performer to be present. The act opens up the possibility to alternative interpretations, which would otherwise be stymied by score or stand. Whether one is a glass blower (Sennett 2008, 176), a violinist (Kimura 1995, 71), or a digital musician (Tanaka 2000, 399), the goal is more or less the same—developing an inner sense of intuition that enables a sort of artistic fluency.

2. Configure the instrument to fit the performance paradigm

Instrumental DMI performance practices evolve. For example, the repetition of performances on the Wacom tablet nurtured a desire to move with the music and develop a clarity of performance, which pushed me to adopt a new hand position with the Wacom tablet (see Figure 4-5). While the idea of relinquishing a hand seems contrary to performance, the natural feel of holding the Wacom in the left hand opened up the possibility of moving the Wacom in conjunction with my body during performance, instead of bending my body around a static object on a stand. That is, the new position of holding the Wacom has enhanced the musical conversation between body and instrument, as I may move with the musical phrases instead of being constrained by an immovable object. The parallel contours in physical movement and musical phrase align the audio and visual domains, which may indicate or affirm musical features for an audience.

3. Add notes (in score or software) to assist with physical expression

Providing notes directly in software or score can assist with performance, although memorizing the work (Value 1) is paramount. For example, Olga Oseth's *Breeze* (2015) includes notes to the performer in the software (Kyma timeline), which serves as a "just-in-time" learning method for performance (Norman 2011, 264). I do sometimes create scores for my DMI works, and my scores and notes exist to aid the memorization process. For example, the score for *AUU (And Uh Um)* (2010) was compiled directly from movement sketches I made while developing the

Figure 4-5: Two configurations of the Wacom tablet in performance. Both images are stills from performances of the same work, *AUU (And Uh Um)* (2010).

composition (see Appendix C).

I have found that muscle memory has been sufficient when re-performing my own work, but scores are helpful when learning other alternate controller pieces. As previously discussed in the performance case study (Section 4.3), I often sketch out a movement score or text instructions when performing other alternate controller works. For example, for Chi Wang's *Ophelia* (2015), I crafted a cue sheet based upon her text instruction score, performance video, and personal communication between the composer. Two of these notes are included below in Table 4.2. Writing down a short-hand notation for my own rehearsals helps reaffirm any aesthetic points that I may fold into the performance (Video 4-7).

Table 4.2: *Ophelia* (2015) cue sheet example

cue4 (@5:30):	finger down (lower left quadrant trigger) slide finger up to upper left after trigger–this gets the finger position out of accidentally triggering sections since each cue afterward is triggered by finger in the lower left quadrant.
cue5 (@5:40):	match the low bass drum hit which happens automatically. This is the hardest bit of the piece, because the visual/audio match has to be 'performed.' The link is not coupled.

Video 4-7: *Ophelia* (2015) by Chi Wang, for Wacom tablet and Kyma, performance by Jon Bellona as part of Technosonics XVII, Second Street Gallery, Charlottesville, VA, October 22, 2016.

4. Review all elements of the performance context

The context of performance is part of the read work—the performance space contains customs and influences (Small 1998), a curated selection of objects (Groys 2009), and the addition or minimization of distractions (Stolet 2015). While not always controllable and not always considered—lighting, dress, cables, show order, and acoustics are part of the reading which make these elements parts of the frame of performance. Even if we deal directly with the human body in performance as Ostertag (2002) suggests, the many *extra-musical* (read *non-body*) elements of the performance remain in play. A list of some of these extra-musical elements is shown below in Figure 4-6. The considerations continue to multiply with the expansion of digital technologies and their varied performance practices.

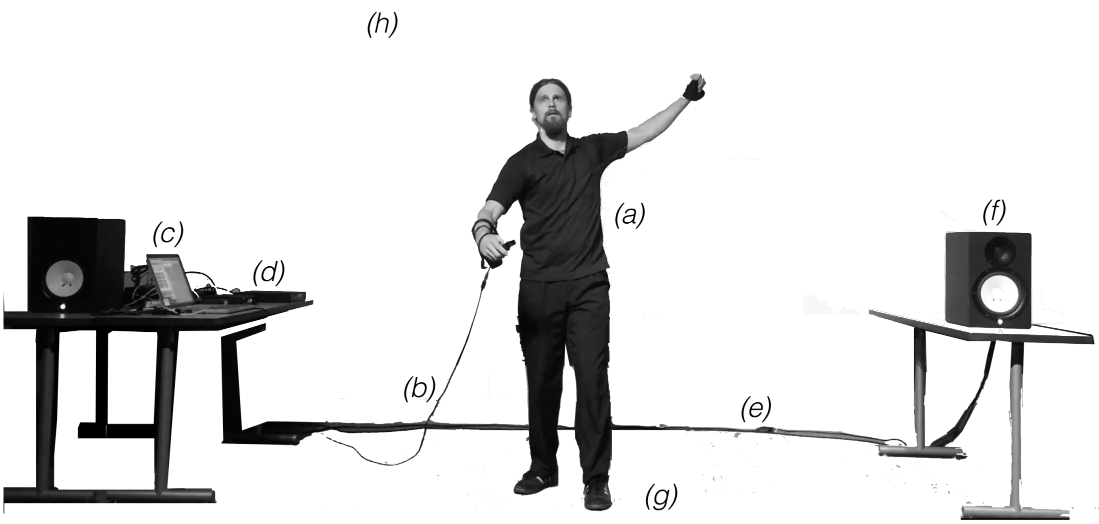


Figure 4-6: Extra-musical elements of an alternate controller performance. On-stage elements may include, but may not be limited to: (a) costume (b) instrument cables (c) performance computer (d) audio I/O and mixer (e) speaker power/audio cables (f) speakers (g) performance space, and (h) lighting

5. Listen intently to develop movement alongside sound activity

The lack of a resonant body on most DMIs impedes feedback between performer and instrument. Listening to the possibilities of sound through the interactions between performer and instrument is crucial to understanding the various ways one may execute a musical work. On DMIs, this listening and learning process fundamentally involves the body of the performer. As philosopher Mark Johnson puts it, "The music of meaning-making is both thought *and* feeling at once, and its notes are the rhythms and tone qualities of our bodily processes" [emphasis in original] (Johnson 2007, 175). Johnson defines three ways in which we experience and learn motion (Figure 4-7):

1. We see [and hear] objects move.
2. We move our bodies.
3. We feel our bodies being moved by forces. (Johnson 2007, 247)

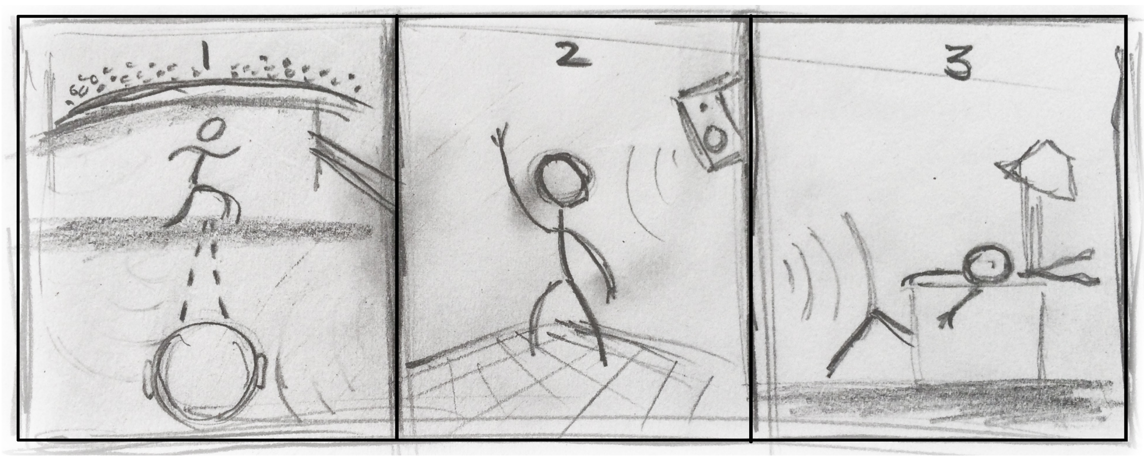


Figure 4-7: Johnson's (2007) three ways of experiencing/learning motion: (1) we see objects move (2) we move our bodies, and (3) we feel our bodies being moved by forces (Johnson 2007, 247). [illustration © 2017 Jon Bellona]

Constantly mindful of the interaction between performer and instrument, composer and sound, or performer and sound, the construction of a DMI involves an intimate coupling between body and sonic vibration. For DMIs, meaning is embodied precisely because the process involves moving, hearing how the body moves in relation to sound, and feeling how sound moves the body. Philosopher Shaun Gallagher puts it another way, "beginnings of the intelligent behavior that we can see... are not only measured by their physical manifestations as bodily processes, they *are* those processes, and are constituted by them" [emphasis in original] (Gallagher 2013, 1). To move is to music, even if the majority of our movements may not seem very musical. Composing music in this embodied way is integral to Physical Composition (Chapter 5) and to an alternate controller performance practice, especially for an instrument like Distance-X (Chapter 6).

6. Move with intent to open up sonic possibility

The physical presence of the performer remains a powerful communication channel (Tanaka 2000, 400). The performer has both the power to articulate and shape digital music because of amplification and the power to shape cultural understanding of alternate controller interactions. With alternate controllers, the performer's body does not necessarily follow customary traditions of musical performance. That is, the minimal cultural knowledge of sound-producing movement on alternate controllers means that the performer's body might become more entangled in the execution and the reading of the work.

Instead of entanglement arising from a cultural standard musical practice, say a flutist indicating phrases with her body, body entanglement for alternate controller performance leans more on performance art practices, where the framing of body and bodily presence shift within the container of each work. For example, Marina Abramović's *The House with the Ocean View* (2002-03), where the artist lived in full view within a gallery space for 12 days, explicitly entangles the body into the work's reading. Everyday actions and pedestrian movements fill the visual space, and there is little color in the objects themselves except for the artist's clothes, body, and the traces of her movement. The frame of the body within the minimal and bare space shifts its meaning—the *pure* presence of body opens up ideas about fragility, habitual customs, and isolation. The flow of time slows through actions and a sluggishly-ticking metronome played from one of the rooms. Abramović's performance decisions were curated and intentional even if not plain to the audience. "She was fasting for the duration and said later this increased her sensitivity and connection to the audience" (Anderson and Abramović 2003, 24). To exhibit one's body within a musical context that continually shifts its frame using technological, historical, and contextual factors, requires an alternate controller DMI performer to actively consider movement. The instrumental body, the performer's relationship to that body, and the presence of the performer's body all reside within the aesthetic frame of performance and therefore become necessary to an alternate controller performance practice.

7. Develop an unfettered belief in the physical self

The alternate controller composition often unfolds in an intimate play between composer and technology. Their musical performances, however, are public acts of expression. Because many alternate controllers require some type of physical enactment, and since many composers are the performers with DMIs, a dissonance may develop between the act of composition and the act of performance. The embodiment of performance, and the belief in the embodied process, may help bridge the crossing of such a dissonant divide.

Physical performance requires physical presence, and the skills of the performer in articulating an alternate controller work can become "the ultimate test of success of a musical instrument" (Tanaka 2000, 402). The outward display of bodily movement (Value 6) serves as an equivalent of the mental movement of the performer, which is more or less expressed in the music. Confidence brewed from a belief in the physical self contributes to the performer-instrument relationship, and for better or worse, helps drive one's performance.

8. Treat rehearsal as performance

The presentation of music on DMIs often requires more than instrumental playing and interpretation. The integration of digital technology, let alone multimedia elements, can require technical, artistic, and presentation skills that help identify or confirm musical features within a given performance. Taking into account the various mental loads of a public presentation, treating rehearsal as performance can help alleviate non-musical factors that may detract from a musical performance.

For example, including the technical performance setup into rehearsal may help mitigate potential technical issues, should any arise during a performance. Some technical considerations to incorporate into rehearsals may include: order of hardware power start-up, order of software execution, running software to mimic time between sound-check and performance, control over equalization and volume for performance venue, and memorization of the work (Value 1). In addition, performances can be further stymied by short load-in times or sound-checks. Including technical setups into rehearsals also addresses these limited preparatory times.

9. Rehearse until sound becomes movement and movement becomes sound

The fluency of proprioception can have deep connections to sound space (e.g., David Rokeby's VNS, Marco Donnarumma's Xth Sense). For DMIs that require physically demanding performances, rehearsing the work requires more than just mental cues, but a full embodiment of the piece. There is no written substitute to affirm this idea. I instead proffer an exercise for the practitioner, an étude for the internalization of how sound becomes movement and movement becomes sound.

Vibrational Exercise: Counting

Simultaneously say and draw the numbers 1 through 9, beginning with 1 and ending with 9. Repeat the process 1000 times. Throughout the process, listen to the arc of the phrase, the connection between each drawn point, and the desired sonic trajectory.

10. Video document the work to assist future performances

Video documentation diminishes the idea of performing—the creation of an object betrays the act of performing.[11] While video documentation may destroy liveness, video can aid the practice of performance on alternate controller DMIs. A DMI doesn't contain the history, traditions, or collective knowledge that a traditional instrument like the violin carries with it. Therefore, video documentation can assist the performer by showing the unfolding actions and subtle movements within a given performance. In learning DMI works without scores, as in the case with *Breeze* (2015) by Olga Oseth and *Ophelia* (2015) by Chi Wang, their video documents were invaluable to the process of learning their works for the performance stage.

4.5 Other DMI Composition and Performance Practices

In working through ideas of repertoire, musicianship, and instrumental design on alternate controllers, two larger composition and performance practices have emerged for me as a composer-performer on alternate controller DMIs: performing full concerts on a single alternate controller and incorporating an alternate controller DMI into group ensembles.

Performing a full concert for a single alternate controller, e.g., 40-60 minutes, challenges the physical and creative capabilities in ways shorter works cannot. Any reliance on gimmick and flair often fade past a single work, and physically demanding DMIs can be exhausting enough to dissuade one from the attempt. Waisvisz would finish even a thirty-minute performance drenched in sweat (Lehrman 1986). In developing a set of works for a single alternate controller DMI, new challenges arose specific to a multi-composition concert, challenges worth

[11] This is certainly true for Peggy Phelan (Dixon 2007, 40) and Laetitia Sonami (Karp and Sonami 2015).

noting here. For one, composition software load times can create gaps between works. Even in rehearsal, any significant time gap between compositions may seem untenable–even one or two minutes of down time can erode audience attention span and break down the air of professional showmanship.[12] Anticipating this gap, I developed two similar methods for navigating the time between works. The first method involves a second laptop comprised of multimedia material (video works, interactive script pieces, as well as fixed media works) for playing between alternate controller works. The multimedia on the second laptop gives the performer time to completely reset the performance computer for the next piece, especially where pieces on the first computer require a lot of processing power. The second method involves interim music—basic tracks played from the main computer—akin to a DJ switching records while the primary LP spins. Interim music may be short one-minute filler works or full compositions between 5-10 minutes in length. I have implemented both methods in practice—the first method at a Wacom tablet and Kyma concert at Dartmouth College in February 2015, and the second method as part of my shows for Distance-X (Chapter 6).

The incorporation of a solo DMI practice within group ensembles is a second emerging practice, where the reuse of the same (or similar) DMI for solo performances is applied to group improvisation settings and contemporary ensembles. Throughout 2016, I developed performance software using Max/MSP to integrate the Wacom tablet interface as part of my group work with Null Set Ensemble and the University of Virginia New Music Ensemble. The performance software, *WacomGranular*, is a customization of Cycling 74's granularized.maxpat abstraction.[13] I customized underlying code, created dependent abstractions, added inputs/outputs, smoothing, audio effects, sample banks, and performance presets in order to satisfy improvisation needs and interpretations of graphic and video-game scores within ensemble performances.[14] The *WacomGranular* software relies on *s2m.wacom* and *s2m.wacomtouch* externals (Métason

[12] In popular music, one sign of showmanship is an individual or band's ability to transition between material. For example, a detractor of Nick Drake's live performances was Drake's inability to engage his audience between songs. As producer Joe Boyd notes, "He was an incredibly shy performer, and would often spend agonizingly long minutes on stage, silently retuning his guitar, and losing the audience's attention" (Mars 2014).

[13] The original abstraction, void of any customization can be accessed in the Max folder, which can be found with the file path: Applications > Max > examples > sampling > granular.

[14] The affordance of drawing with a pen on the digital tablet made graphic scores and video-game score works easier to code for than standard notation. One of the Wacom tablet's strengths is appropriating motor memory, taking advantage of a learned writing practice, even if the movements are not syntactical in nature.

2016) and includes objects from my mixer.* and jpb.mod.* Max packages (Bellona 2015a,b).

Since the development of *WacomGranular*, I have performed with this DMI as part of the New Music Ensemble's performance of Cornelius Cardew's *Treatise* (in its entirety),[15] and as part of gigs with the free improvisation group, Null Set Ensemble, throughout Charlottesville, VA. Most recently, I used *WacomGranular* to record material with Null Set Ensemble for an upcoming music release. A rough mix snippet of this material is provided in Audio 4-1. The recording with Null Set Ensemble included members Kristina Warren (voice & electronics), Christopher Luna (prepared electric guitar), Alex Christie (tenor sax), Ryan Maguire (prepared pedal steel guitar), Kevin Davis (amplified cello), Jon Bellona (Wacom tablet & *WacomGranular*), and Max Tfirn (percusssion).

Audio 4-1: Excerpt from an upcoming release by Null Set Ensemble. Recorded at The Sound in Charlottesville, VA on May 8, 2017.

This chapter has focused on alternate controller composition and performance practices that build from my own artistic practice on alternate controller DMIs. The examples further underscore the body in the execution of a DMI composition and performance practice—the human performer is central to my alternate controller practice, a position that I understand can be nuanced and subjective. Throughout this dissertation, I have asserted the human performer's importance in an alternate controller DMI musical practice, and under the siren's call of technology, that assertion cannot be stated enough. Guy Garnett sums up the point well:

> But if the human performer is still actively engaged in the production, there will at least be a countervailing tendency to see the work as having meaning or significance to that human element and therefore to judge it based on that significance. In this sense, it is important that the technology be focused on extending human capability and not simply extending technology for its own sake. (Garnett 2001, 31)

This notion, that physical presence informs the design of alternate controller technology and its musical reception, places the human at the forefront, and it is time to directly address the concepts of corporeality related to music composition. The next chapter, Physical Composition, ties the creative composition act to physical act, a joint body-mind process in composing on

[15] New Music Ensemble, Cornelius Cardew, *Treatise*, Old Cabell Hall, University of Virginia, Charlottesville, VA, April 13, 2017. http://music.virginia.edu/new-music-spring-2017 (accessed January 4, 2018)

alternate controller DMIs.

Chapter 5

Physical Composition

> Movement and the registration of that movement in a developing proprioceptive system (that is, a system that registers its own self-movement) contributes to the self-organizing development of neuronal structures responsible not only for motor action, but for the way we come to be conscious of ourselves, to communicate with others, and to live in the surrounding world.
>
> Shaun Gallagher (Gallagher 2013, 1)

Composing is a physical act. A composer choreographs bodies; he notates actions on instruments. The act affirms that we are embodied beings (Gallagher 2013; Johnson 2007). *Physical Composition* describes the active conversations between movement and sound among composer / performer / instrument carried out during the DMI composition process. Physical Composition considers the composer's and the performer's effort in the creation, and in the translation of sound and meaning. For DMIs, Physical Composition is a conscious method to leverage the physical resistance of the performer in digital music.

While the previous chapters have described Physical Composition from the outside, how do these activities occur *inside* the creating body? What does Physical Composition *feel* like? This chapter engages a neurological, philosophical, and technological discourse around the body, accounting for the choreographic body as compositional agent, a force implicit in the act of writing music. Physical Composition strives to embrace our body in the creative process by moving away from the common view of composition as a mental act—a translation of sounds heard internally—and moving toward music that emanates from the body.

Physical Composition may address any number of contexts of the DMI composition process, including: the development of a new hardware instrument that requires learning the object's physical affordances (Norman 2002); the choreography that supports musical activity; the mapping of software to the performer's sensor input; the composition of music using a potentially unfamiliar interface with potentially unfamiliar movements; and the musical performance. Physical Composition describes the active consideration of physical attributes throughout the entire DMI composition process, even if one or more of these activities I have just described is not present.

By using the two terms together, physical and composition, I indicate that the act of composing originates in the body and acknowledges the conscious involvement of the body in the creation of music, in particular, the creation of music on alternate controller DMIs. Physical Composition is a way of composing—an intentional use of the human in our musical practice that deliberately leverages the body. And as will be shown, physical body activity (e.g., movement) and composing are one and the same.

5.1 How Movement Informs Design

> Body-in-action tends to efface itself in most of its purposive activities. To the extent that one does become aware of one's own body, by monitoring or directing perceptual attention to limb position, movement, or posture, then such awareness helps to constitute the perceptual aspect of a body image. Such awareness may then interact with a body schema in complex ways (Gallagher 2013, 26).

First and foremost, Physical Composition acknowledges the body as part of our experience in the act of music (composing, performing, listening). Physical Composition isn't just a concept; movement makes up who we are—our consciousness, our expressive being, and our power to communicate (Gallagher 2013; Johnson 2007).

Gallagher (2013) and Johnson (2007) use metaphor, neurological case studies, and phenomenological debate to calculate how the body becomes and serves as idea. The concept of a physical body and the idea of that body are rooted in Spinoza, who claimed as false the dichotomy between body and mind in his seminal work, *Ethics* (Spinoza 1996). For Spinoza, a thing and its idea are "*one thing*, expressed through two attributes" (Lord 2010, 56). Experience unfolds and can be known either in its idea, the attribute of thought, or in its physicality, the attribute of extension. This implies that we have only two ways—the two attributes—to understand how an experience or activity unfolds.

The notion that parallel streams of activity spool out through the attributes of thinking and extension is Spinoza's idea of "parallelism" (ibid., 53-7). Parallelism stems from Spinoza's Proposition 7: "The order and connection of ideas is the same as the order and connection of things" (Spinoza 2000, 117). For musical performance, we may consider how the causality of music unfolds from the performer. One moves *and* has the idea of that movement—the same thing expressed in two different ways. One plays a sound *and* has an idea of that sound—the same thing expressed in two different ways. Figure 5-1 depicts how Spinoza's concept of parallelism is applied to sound and movement.

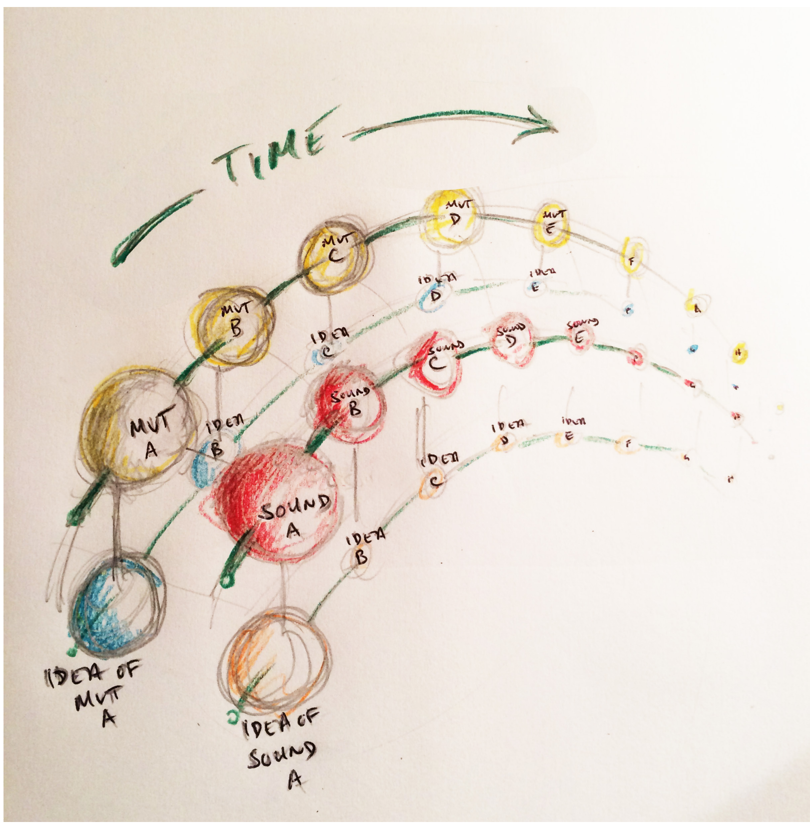


Figure 5-1: Spinoza's concept of parallelism applied to sound and movement. [illustration © 2017 Jon Bellona]

Moments of movement and sound unfold as both physical extension and idea. This is how Physical Composition works within a performer. For example, when I perform *SG6VS* on

Distance-X (Video 6-6), I move my arms controlling sensors, and I have an idea of the trajectory of my arm movement. I listen to the sound I perform, and I hear my idea of that sound. It is through my body that I interrogate my movement and its idea and navigate between the sound and my idea of the sound. Both movement and its idea and sound and its idea are the expression of the same thing, unfolding at the same time. There is no divide between mind and body.

Idea and thing are the same, but it is important to note that body movement and sound exist as two different streams of causality, occurring at the same time. Movement and its idea are one causal stream, and sound and its idea are another. As the performer, I embody the unfolding of the two causalities as I explore my body movement and idea and as I explore the sound and idea. The two streams of causality are why movement and sound are drawn along their own arcs in Figure 5-1. For the audience of a work like *SG6VS*, there can exist a perceptual overlap between sound and movement, whether or not there is direct link in causality between the two. Figure 5-2 depicts the perceptual overlap between the two causalities of body movement and sound.

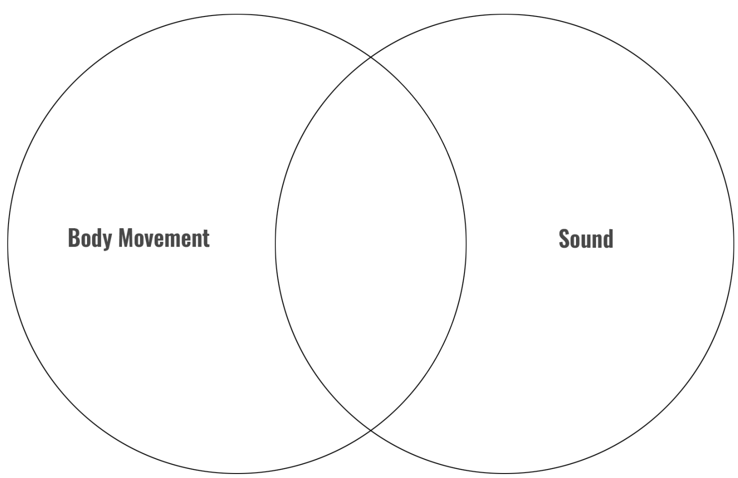


Figure 5-2: The perceptual overlap between the two causalities of body movement and sound

How the performer is, or becomes, conscious of each of these two streams reveals another layer of embodiment, proprioception. Proprioception describes our capacity to understand the parts of the body in relation to one another, especially to execute physical actions. The understanding of "proprioception can mean either non-conscious *information* or a form of conscious *awareness*" [emphasis in original] (Gallagher 2013, 7). The different modalities of awareness make this type of "intracorporeal information" important in perception, judgment, and empathetic understanding (ibid., 7-9).[1] One common proprioceptive exercise involves balancing a ball on top of one's limb while rotating the body 360° on the floor (Feldenkrais 1977).[2] The combination of rotating one's body on the floor and balancing a ball upon the sole of one's foot requires an active process of proprioception, the synchronization and sequencing of body information and action to successfully complete the task.

Some philosophers describe perception of movement (the internal-external relationship of conscious factors) alongside execution of movement (the internal-external relationship of pre-conscious factors) through the adoption of terms like "body schema" (Merleau-Ponty 2009), "mind-body" (Johnson 2007), and "body image" (Gallagher 2013). Gallagher (ibid.) works through the confounding of terminology but agrees on how our "beliefs, attitudes, disposition... form part of an intentional system" (ibid., 25).[3] This understanding of body as it relates to one's body, a "reflexive intentional system" (ibid., 28), supports how Physical Composition on DMIs attempts to treat the body as an equal, creative force. By bridging the divides between 'mind' and 'body,' we may take seriously a musical discourse between the moving body and sound, even within digital systems.

Physical Composition does not endorse a motor theory of perception.[4] However, bodily movement and the motor system do "influence cognitive performance" (ibid., 9). Physical Composition emphasizes body awareness and recognizes that a successful musical performance requires automatic processes in the body to happen. This training is what Gallagher calls "a consciousness of bodily movement to train body-schematic performance" (ibid., 35). For music composed on Distance-X (Chapter 6), sonic phrases emerge from physical body movements.

[1] I discuss embodiment with full acknowledgment of the rich and complex differences between bodies. Bodies may be, as Weiss (1999) describes, "marked" by race, gender, social-class, age, technology among other differences (ibid., 2-3). It is outside the scope of this dissertation to delve into these rich differences, but we should not omit different body types from our ideas of body while working through a discussion on embodiment.

[2] Many of Moshé Feldenkrais Awareness Through Movement (ATM) exercises involve some form of proprioception.

[3] Again, it should be noted that wide differences in beliefs, culture, as well as physiological and physical dispositions can form complex and rich differences of body image (ibid.).

[4] Motor theories of perception hypothesize that understanding is contained in the motor system. For example, a motor theory of speech perception posits that perception occurs through the gestures of the vocal tract rather than the sound patterns themselves (Fowler et al. 2003).

How I work in codifying these movement phrases shapes the arc of the musical work as much as the sound. To move is to contain "all of the things that go into meaning—form, expression, communication, qualities, emotion, feeling, value, purpose, and more... the conditions of experience... and art is a culmination of the possibility of meaning in experience" (Johnson 2007, 212).

The link between body and technology follows a similar logic, where technology of the performer becomes part of her attribute of extension. Technology extends the body—the cane of a blind man is part of the ecology of his body (Bateson 1987, 256, 324, 466)—and thus technology becomes part of the human. The perceptual feedback loop includes the digital technology (Hayles 1999, 14), and a body of technology is now embedded within a body of perception.

The view that the body is extended by instrumental body is formulated similarly in concepts across compositional practices. For example, Armstrong (2006) outlines five criteria for embodied activity with respect to DMIs: situated, timely, multi-modal, engaging, and emergent (ibid., 8-10). Donnarumma (2016a) describes three modes of embodiment in musical performance—vibration, flow and automaticity—which he calls "configuration modes" (ibid., 120). Donnarumma details his conditions as ways of knowing inside of a sound performance. Like Armstrong (2006) and Donnarumma (2016a), I agree that musical performance is served by a performing body. By remaining in active dialog with the movements required to make the sound, we empower the bodily, perceptual, and enactive aspects of musical performance (for further discussion, see Section 4.4: Performance Practice Values on Alternate Controllers). Musical performance requires trust in the performing body.

5.2 Shadow Form

A DMI system contains the unconscious information of a digital body – the digital bits of body movement sampled by electronic sensors (Chapter 2). The digital trace of a body, its shadow, acts as material a digital composer works with. DMI sensors filter the moving/acting body. "The movement that motion capture seeks to record is always physical—it is never anything other than physical and real-time movement" (Sutil 2015, 198). Understanding that there are traces of the body within the bits of a digital system, the composer can make the body's digital trace apparent in sound. The composing of a digital body is the *shadow form*.

The body's digital shadow may be made explicit, as with Fiebrink (2009), who uses machine learning to train identification of postures, leveraging neural networks to continuously compare performer actions against previous ones. In this way, machine learning ties the body directly to actionable outputs. The digital body may also be cut up and reassembled, as with live coding languages like ChucK (Wang and Cook 2004). Live coding abstracts a user's movement into blocks of functions and case statements, which further mediate the performer's bodily actions from sound through the modular structure of object-oriented code.

Physical Composition defines a way of working with sonic material—an attitude toward possibilities of movement in sound and sound in movement. This principle is best demonstrated on acoustic instruments, where instruments inform the compositional and performance process *because* the movement is embedded in the sound. One has to change the position of the body in order to change the sound. I wrote *Immaterial Vamp* (2017) in order to explore this interplay between physical and sonic action. By focusing on slow changes through repetition, shifts in the physical performance result in sonic alterations, and vice versa. We hear sound as the responsibility of the performer, the performer who juggles sonic envelopes and phrases, shaping and molding the immaterial through physical and sonic activity.

Audio 5-1: *Immaterial Vamp* (2017) for New Music Ensemble and includes *Wacom-Granular*. Performance recorded in Old Cabell Hall, University of Virginia, March 25, 2017.

Movement remains in the shadows of our musical choices. If we choose a different sensor, we remove or add movement possibility as control. If we choose a different mapping, we accent or obfuscate different movements in their potential to correlate to sound. If we choose different sound outputs (i.e., samples or synthesis models), we change what movement-sound relationships will exist, what they might offer toward meaning, and how they might evolve over time. The use of alternate controller digital technology to facilitate composition to generate sound through the lateral, saggital, and vertical movement of our bodies, involves a negotiation of the body's digital shadow. Certainly, one may take advantage of the performer's kinesphere while developing a new instrument instead of being constrained by the physical demands of a pre-existing set of movements. In a blank slate choreographic space where anything is possible between movement and sound, including its severance, one may desire a "clear understandable coherence" between body and sound (Tanaka 2000, 400).

Musicians across genres express a desire to tether body and sound within musical performance. For example, Pete Townshend of The Who explains his reasons for incorporating movement into his guitar playing in an interview with Murray Lerner. "I didn't bother too much about the notes that I played. I bothered more about what I was doing physically, about the shape of the movements that I did.... I wanted to convey a sense of energy, as well as a kind of visceral sense."[5] One of Pete Townshend's signature moves is a vertical leap, where Townhend lands on the ground and strums the guitar in time with the pulse of the music. Townshend's *analog amplitude modulation* signals the musical feedback loop outward to reach fellow musicians and audience. This example can be seen in the outro of Pete Townsend's performance of *A Friend is a Friend* on *Late Night with David Letterman* (originally aired June 28, 1989) (Video 5-1).

Video 5-1: Example of Pete Townshend's physical movements communicating musical time and signaling amplitude modulation. Performance video of *A Friend is a Friend* on *Late Night with David Letterman* (originally aired June 28, 1989).

Movement isn't just for effect or theatrics but intertwined into the playability of an instrument that may "affect the musical phrasing and articulation" (ibid., 402). For Tanaka's BioMuse, the instrument requires physical action to perform, but this behavior aids understanding of his musical device.

Today, the field of live electronic music continues to grapple with the balance between the human body and technological systems, between human choice and algorithmic choice, and between physical effort and technical ease. Often these scales are tipped away from the flesh. For DMIs, where effort can become un-tethered from sound, the moving body as cognitive force serves as an important reminder to how important the body is to a DMI musical practice. The physicality of music adds to the shared understanding of the music through the lens of the shared physical understanding of our experiences.

[5]Pete Townshend, interview by Murray Lerner, *Amazing Journey: The Story of The Who*, NBC Universal, 2007. https://www.youtube.com/watch?v=CwHM0vzP-GQ (accessed February 14, 2018).

5.3 Key Frame Anatomy

Physical Composition leverages digital technology to connect the flow of movement-sound experiences together, which may be best understood through the concept of key frames. Key frames are reference points in time that serve as connectors for animated movement. For alternate controller DMIs, digital movement represents the performer's applied digital body; the interpolation of digital movement between key frames relies, in part, on the DMI performer. Anatomically, our digital music body consists of different types of key frames: presets, moments, and snapshots. *Key Frame Anatomy* constructs a musical body by connecting compositional structure and muscular movement with digital tissue.

Key Frame Anatomy
Presets — control states
Moments — sound / movement
Snapshots — data samples

The tripartite structure of Key Frame Anatomy builds the skeleton of a DMI performance. First, there are "presets," the predetermined values of controls which a performance steps through. DMIs are well-suited for the storage and recall of data because of their reliance upon digital technology. While Chapter 3 described storage and recall of data streams in small memory buffers, larger system recall often comes in the form of presets. For example, Michel Waisvisz used presets to actively compose with his first version of the Hands (Bellona 2017). As quoted in Lehrman (1986), Waisvisz explains, "'I know where I start and the trajectory of where I want to go in each performance, but I will sometimes leave things out, or add, or repeat things. Actually, I find that compacting is usually best'" (ibid., 21). Waisvisz used MIDI control change messages to alter synthesizer presets, which gave him the ability to compose for performance. Waisvisz could cycle forward or backward to different sonic timbres based upon his knowledge of preset patches; these presets served as a performance road map of timbre.

Presets may also be structured, as with electro-acoustic compositions in which accompanying software is triggered by an engineer or composer.[6] Structural presets may include

[6]Two examples include Elainie Lillios' *Among Fireflies* (2010) and Philippe Manoury's *Pluton* (1988). One may watch

technological items such as the ranges of digital data (input/output), control state settings, audio banks used in playback, or score advancement.

Second, Key Frame Anatomy consists of "moments," which describe attentive consciousness as nodes within the stream of causality (Lord 2010, 56, figure 2.1). The performer moves between movement and its idea and sound and its idea over the course of a performance (Figure 5-1). These moments can be notated or described from the perspective of the composer-performer.

By way of music example, the performance case study of *Breeze* (2015) in Chapter 4.3 demonstrates the application of "moment" key frames. In my own performance notes, I sketched out landing points to enable the interpolation of sound (Figure 4-4), and each sketch served as a key frame "moment." In order to overcome the weakness of the notation, I applied values asserted in Chapter 4.4, for example, *memorizing the work*, which actively guided my performance interpolation of data-as-sound.

Key Frame Anatomy also consists of "snapshots," the sampling of continuous movement / experience at data rate. How digital data is conditioned can affect sonic mappings. For example, Audio 3-7 and Audio 3-8 demonstrate how linear and non-linear scaling affect sonic output, and Chapter 3 describes various tools for addressing digital data.

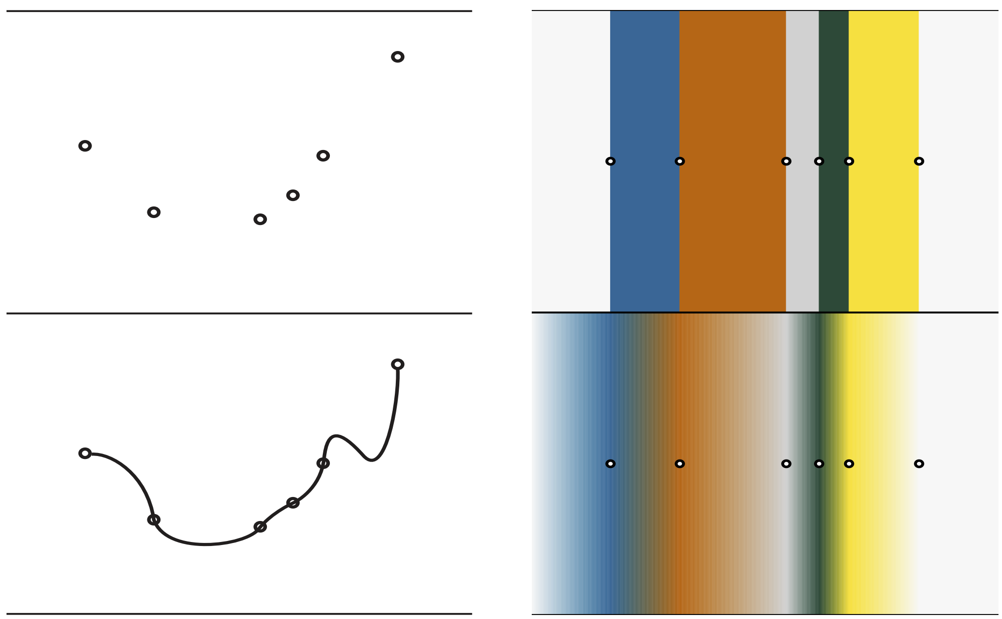
The performer may not be entirely aware of "snapshot" key frames. Like shadow forms, "snapshot" key frames are the hidden body in digital form—the quantization of angles and curves from a sensor that represents our movement. The introduction of noise, digital jitter, may occur to such small degree as to be imperceptible. Key Frame Anatomy acknowledges the limits of technology and human cognition. The pathways of digital performance may require interpolation to smooth out digital jitter, or involve rapid updates to trick us into perceiving continuous flow (like the standard rate of 24 frames per second in film that trick our brains into perceiving continuous motion).

Key frames used as a notational format contain the negative potential to stand as ends in themselves. Like music notation, key frames run the risk of becoming the ossified material they are designed to dissolve. For Physical Composition, key frames are meant as throughputs to activity (moving as dynamic object), instead of becoming the activity (production of a static

Among Fireflies online at: https://www.youtube.com/watch?v=B8wSLrCXcXg (accessed January 24, 2017).

object). Key frames signal potential in the connecting of lines rather than in the creation of isolated dots.

The animation concept of ‘key frames,’ or frame-by-frame interpolation, can help demonstrate movement potential between static points in time. By defining start and end locations, key frames identify the transitional spaces within which interpolation occurs. Figure 5-3 depicts key frame animation, where six points are connected with interpolated data in two different ways.



(a) Key frame movement animation

(b) Key frame color animation

Figure 5-3: Interpolation of movement using key frames

The two figures depict the same six points in X-coordinate space. The first figure depicts positional movement along a line, and the second figure depicts color shifts of RGB data. Different trajectories or pathways may unfold between key frames. Key frames encode motion into a cognitive form, a cohesive digital representation of movement that helps form idea and sound; the interest is in how these key frames are connected. A digital body acting as, or guiding, the interpolation creatively articulates connection between key frames.

The process of Physical Composition works to shape itself by moving from physical actions to static digital samples back into dynamic sonic activity. For example, my 2011-13 work on the Microsoft Kinect began with analyzing human movement at regular intervallic rates in order to command continuous musical actions. The process of composing with the 3D camera technology emanated from the body, and the body demanded space for its involvement. That is, the discourse between body and sound led to using distance between joints as a hallmark control variable. In the simpleKinect system that I designed (Bellona 2012c), distance magnitudes between joint vectors served as continuous controls for musical parameters,[7] and I continued this work on Distance-X (Chapter 6).

Current trends in digital technology include the recognition of movements via neural networks (Bloit et al. 2009; Fiebrink 2009; Young 2008), the development of gesture-actuated DMIs (Robinson et al. 2015; Schacher 2013), and interpolative mapping strategies (Bullock et al. 2015; Françoise et al. 2014), all of which extend how key frames may directly integrate with body movement. For example, machine learning classification (e.g., KNN or decision tree) for posture recognition in performance space exemplifies how technology works with the concept of key frames and digital body. Instead of using notational "moments" that rely on the performer, the computer *listens* for learned 'postures' of dynamic movement that aid the compositional framework of a musical interaction.

By understanding movement as both extension and idea, the *physical composition* of movement integrates ideas, bodies, and technologies into a holistic perspective that drives them forward together toward a singular musical act.[8] The next chapter, Distance-X, will describe a new DMI that marries Physical Composition and its respective performance practice values with the technological configuration of motion (toolkits, structures, and control paradigms). The design prototypes and their sounds formulate a process that musically define and embody Physical Composition. The effort ties choreographic space to composition space, digitally re-sampling bodily movements into intentional sonic movements.

[7]A joint vector is a three-dimensional geometric point containing magnitude and direction and describes one of fifteen joints of the human body available on the Kinect camera via OpenNI (Borenstein 2012).

[8]One concept I do not address in this chapter is the sexuality of the body, either in terms of body physicality or body movement. Sexuality and stereotypes around sexuality may arise during one of the compositional processes of Physical Composition, and as such, sexuality may be addressed at that time. Unfortunately, the broad topic of sexuality falls outside the scope of discussion here; however, I feel it important to acknowledge the role that sexuality may play within Physical Composition.

Chapter 6

Distance-X

I slowly move my hands apart. A sound opens. The envelope emerges from the hands, evolving as I change the space between my palms. I sense the changes of the movement, tinkling within the tendons of my arms, and I sonically embrace the expansion of the sound. There seems little difference to touching the strings on the guitar, or breathing outward into the flute. Outward and inward, my movement is tethered to the instrument. My body is tied to the sound experience. Now, here, my physical movement shapes sound. I move and respond. Choreograph and reflect. Pose and listen. I bring my hands together, closing the sound.

Inside movement, active listening is paramount. I hear my body open, just as I hear the sound grow louder. I internalize the sound. The sound soon will become the only thing that holds the movement up. I focus on maintaining the sound... I listen to know if there is space to continue moving. I listen to know when the sound and the movement are complete.

I strive to become a carrier of a sound. I physically push a sound into the space. The sound will eventually fade (it's inevitable), but the choices I make with my body-idea, the output of which is my 'choreographic sound,' has an opportunity to exist outside my body. Call it cross-modal persistence, call it spatial understanding, call it noise, music, whatever. I move to understand how to sculpt sound, and the feedback loop of sound-movement informs the patterns and the pathways which become the work. This is the space in which I create, and when the clutter of technology fades away, sound vibrates within my body and my body simultaneously vibrates as sound waves pulsing out in time and space.

Distance-X is a digital musical instrument that translates choreographic movement into musical sound. The impetus behind creating the instrument stems from the desire to tie together choreographic space with composition space, whereby sound and movements co-exist as a part of the composition process. The musical instrument is meant to increase the overlap between creative sound and kinespheric space, such that movement helps inform creative choices in sound, and sound helps inform creative choices in movement.

Distance-X represents how I work musically within the realm of Physical Composition. The instrument aids the development of sonic phrases emerging from my physical body, improves how I shape movement in parallel with the arcs of musical phrases, and stresses my attempts to extend or elongate movement inside envelopes of sound. Frustrated with the near absence of physical movement in the act of composing electronic music and excited by the visceral connections to body that alternate controllers like the Wacom tablet have afforded me, I've spent the last several years researching, scripting, and contemplating instrument designs. Inspired by the amplitude mappings of Michel Waisvisz's The Hands (Waisvisz 1985), the frenetic causality of Chikashi Miyama's Seven Eyes (Miyama 2008b), and the physical brutality of Marco Donnarumma's Xth Sense (Donnarumma 2011), I've worked toward a relatively simple design that blends large arm movement control with basic push and accelerometer controls.

Distance-X uses the word 'distance' in its name not simply because I sample hand distance as an instrument control. The term describes the differing relationships between performer and musical instrument: the physical distance between the performer's hands in kinespheric space; the relational distance between composer and performer; and the technological distance between effort and sound. Distance implies a kind of 'space between,' and my musical activity explores this space. I compose with the activation and alterations of distance.

6.1 Hardware

In order to streamline mental activity during the composition and performance processes, I took Distance-X through several prototype versions over a 14-month period. The design prototypes had two specific aims: 1) incorporate natural wrist and arm movements for tying choreographic space to composition space, and 2) provide full finger access to buttons and joystick controls with stable control-state switching. Table 6.1 outlines the chronology of this prototyping process.

Table 6.1: Distance-X hardware prototype timeline

Version	Input	Works	Date
1.0	Two Video Game Controllers	Torch	Feb. 2016
2.0	Plastic Mold, Bluetooth Keypad, Joystick	-	Nov. 2016
3.0	Gametrak arm attachment	-	Jan. 2017
3.1	Gametrak + Wiimote	TCF4 (Study 1)	Feb. 2017
		SG6VS	
		Trump Is A Fascist	
		CDM v2	
		HMW-mult3	

For the first prototype, I chose off-the-shelf components and attached two video game controllers to my wrists (Figure 6-1). I incorporated this prototype into a short, live section of *Torch* (2016), presented at (sub)Urban Projections at the Hult Center in Eugene, OR on April 17, 2016 (Video 6-1).

Figure 6-1: Distance-X (v.1.0), two video game controllers strapped to wrists. The prototype uses store-bought components (USB video game controllers, mounting hardware, tape, and wrist bands).

Video 6-1: *Torch* (2016) performance video, which depicts the initial Distance-X prototype (two video game controllers attached to performer's wrists).

After attaching the video game controllers to the wrists, I was unable to easily switch between material using the computer keyboard/mouse. I also gave up my ring and pinky fingers of both hands to trigger buttons. This design feedback led me to develop a wrist mold using Thermomorph Moldable Plastic Pellets (Figure 6-2). This second hand/wrist prototype included the plastic wrist mold, weight lifter's wrist wraps for attaching the interface to the wrist, a Bluetooth keypad resting on the plastic mold, and a 2D joystick attached to an Arduino Nano for thumb control.[1] While I was able to incorporate all fingers easily into the interface with the Bluetooth keypad and effectively send discrete messages to the computer, the design failed to enable adequate, unencumbered wrist movement. When I discovered that I lost wrist movement from the design, and lacking satisfactory sonic trials, I quickly abandoned the prototype.

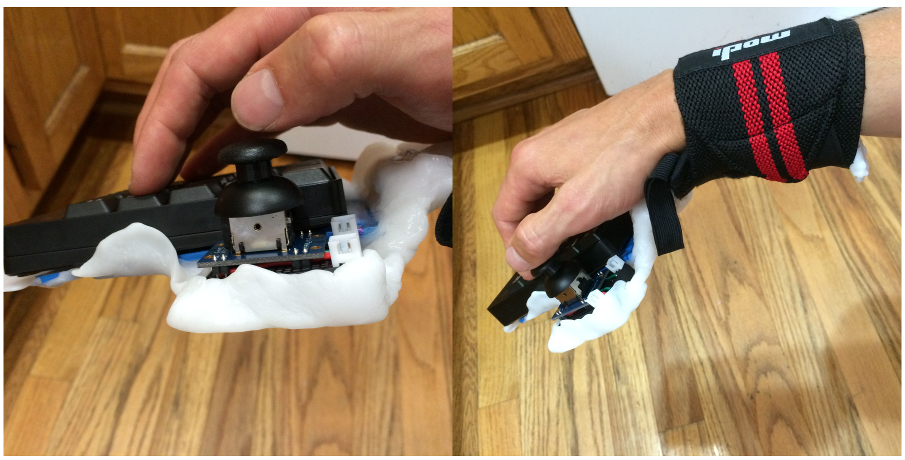


Figure 6-2: Distance-X (v.2.0), Bluetooth keypad and 2D joystick set into plastic mold

For the third prototype, I focused on the goal of merging arm movement space to sound space. I knew from my previous arm-tracking work with the Microsoft Kinect (Chapter 3, Section 3.6.4), that I desired a stabler system for sending vector distance between joints, specifically, the distance between the hands. This desire led me to the Gametrak controller, which I had used previously as a distance threshold trigger on *Convulse, Die, Mourn* (2015) (Video 6-2).

Video 6-2: *Convulse, Die, Mourn (CDM)* (2015) for Kyma, Gametrak, and Wacom tablet. Performance at the 2015 International Computer Music Conference in Denton, TX, September 29, 2015.

[1]Arduino, https://store.arduino.cc/usa/arduino-nano (accessed March 3, 2018).

In order to utilize the Gametrak for this design solution, I pulled out the four, corner weights of the controller and sawed the device in half at an angle complementary to the angle of the forearm (Figure 6-3). The angle was measured with the forearm raised in front of and perpendicular to the body. The three controls of the single joystick (XYZ), were wired to an Arduino Nano v3.0 ATmega328 board compatible with the Arduino IDE (Figure 6-4).[2] The board was screwed into the body of the Gametrak, and the USB output attached to a longer USB extender cable for connection to the computer. Two quick release buckle straps were attached to the chassis of the Gametrak for easy fastening of the interface to the forearm. A thin cardboard layer was placed over the cut opening of the Gametrak for comfort and to protect the electronics from sweat and static electricity. Figure 6-5 depicts the completed arm interface.

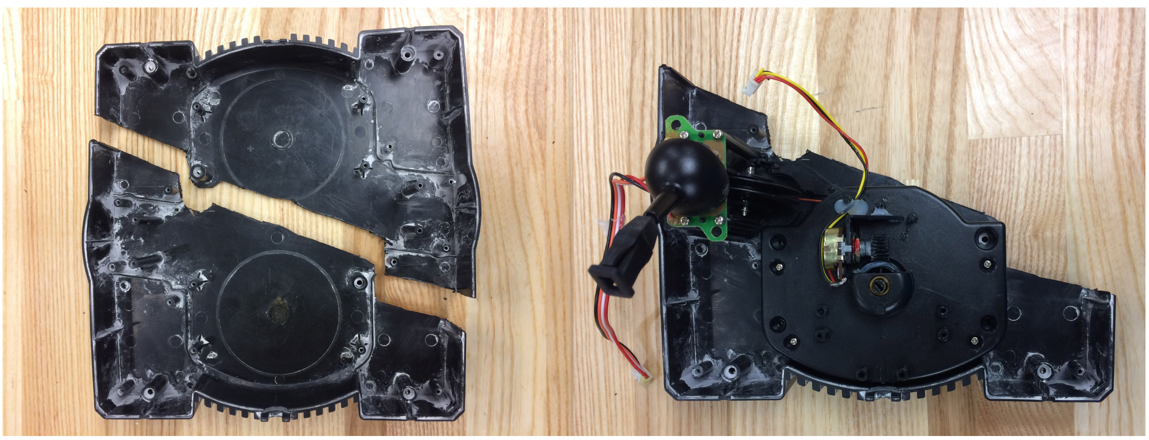


Figure 6-3: Distance-X Gametrak hack. Cutting the controller in half left one joystick available. The cut was made at an angle in order to attach to the forearm.

After developing the forearm interface, I returned to prototyping button and wrist controls in order to complete the Distance-X design. For coding simplicity, I chose the Nintendo Wii Remote™ controller for the third iteration of wrist and finger controls. While the Wiimote lacks ring and pinky finger control and does not provide thumb joystick control, the controller does offer enough buttons for changing between control states (i.e., musical sections or performance presets), and transmits accelerometer and gyroscope data, providing *adequate-enough* controls for elbow and wrist movements. Table 6.2 shows the hardware inputs of Distance-X and their affordance of performance control with respect to the performer's movements. Figure 6-6 shows the full Distance-X interface (hacked Gametrak and Wiimote).

[2]Arduino, https://store.arduino.cc/usa/arduino-nano (accessed March 4, 2018).

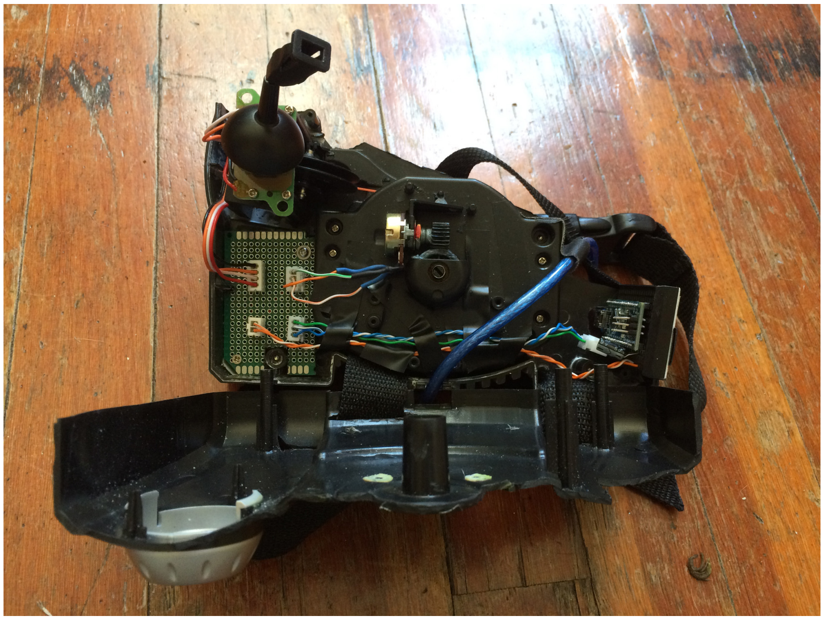


Figure 6-4: Distance-X Gametrak hack, with wired electronics to Arduino Nano. Joystick and potentiometer share 5V buss power.

Figure 6-5: Distance-X (v.3.0), arm interface, complete with buckle straps and soft forearm casing

Table 6.2: Distance-X inputs

Controller	Input	Value Range	Mvt. Range
Gametrak	X-axis	0-1023*	medium
	Y-axis	0-1023*	small
	Z-axis	0-1023*	large
Wiimote	Accel. Pitch	-1 to 1	medium
	Accel. Roll	-1 to 1	medium
	Accel. Yaw	-1 to 1	small
	A button	0/1	
	B button	0/1	
	Left button	0/1	
	Right button	0/1	
	Up button	0/1	
	Down button	0/1	
	- button	0/1	
	Home button	0/1	
	+ button	0/1	
	1 button	0/1	
	2 button	0/1	

*0-1023 represents 10-bit configuration of joystick controls on Arduino IDE platform. Out-of-the-box, Gametrak's electronics offer a 12-bit range, 0-4095.

Figure 6-6: Distance-X as worn by the author

6.2 Software

There are three main software applications used to interface Distance-X hardware to sound synthesis: Max/MSP,[3] OSCulator (Troillard 2015), and Kyma (Scaletti and Hebel 2017). Max/MSP and OSCulator are used to parse and *cook* hardware input data and Kyma is used for mapping data to live sound synthesis.

Joystick data (XYZ) from the Gametrak are sent via Serial into Max/MSP, where data-streams are normalized and smoothed, before being sent as OSC messages to Kyma. Figure 6-7 shows the software interface with toggles for composition-specific controls. I chose to place composition-specific routing into separate patchers in a single Max/MSP file in order to streamline composition of new works, and to reduce performance time between works (one .maxpat file to switch between compositions). OSCulator handles Nintendo Wiimote connections via Bluetooth, sending most of the data directly to Kyma, with a few buttons reserved for sends to Max/MSP. These reserved buttons for Max are used to switch between control states in both Max and Kyma.

The Max patch requests data from the Gametrak every 10 ms, and prior to mapping, each datum is averaged over the last four data points (40 ms). Using jpb.mod.scale Max abstraction objects (Bellona 2015b), X, Y, and Z-axes are exponentially scaled to between 0 and 1, before these three data points are sent as OSC messages to Kyma. The patch additionally calculates

[3] Cycling 74, Max/MSP, https://cycling74.com/products/max (accessed March 3, 2018).

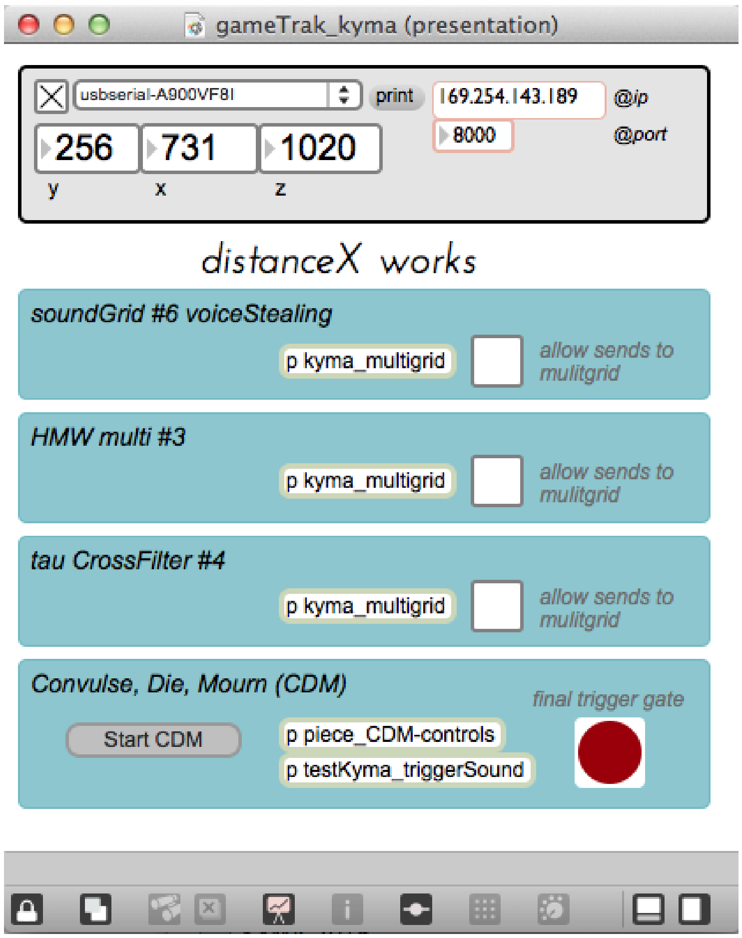


Figure 6-7: Max/MSP software interface for handling Distance-X data input/outputs (Gametrak joystick and specific Wii buttons) with toggles for composition specific controls

direction and acceleration of the Z-axis and sends these two data points out as OSC messages. All other portions of the Max/MSP patch deal with specific composition messages. The majority of these messages are control-state functions controlled by Wiimote buttons -, Home, and +.

Distance-X integrates Kyma's Multigrid for its live framework. The Multigrid is a "navigation system... that can contain multiple Tracks that play simultaneously" (Scaletti and Hebel 2015, 149). Figure 6-8 shows a view of Kyma's Multigrid, reflecting design and control similarities to Ableton Live's mixer interface.[4] The Multigrid tracks can contain multiple Sounds (i.e., audio presets with varying control-states), which are selected by Wiimote buttons through the main Max/MSP patch. (For more on presets in relation to Physical Composition, see Chapter 5.3, Key Frame Anatomy.) The Multigrid contains unique Sounds on each track. The use of multiple tracks allows these Sounds to be easily combined and re-combined, and sound-movement ideas can be quickly tested. For composing on Distance-X, the Multigrid supports development of movement alongside sound activity (Chapter 4.4, Performance Practice Values on Alternate Controllers).

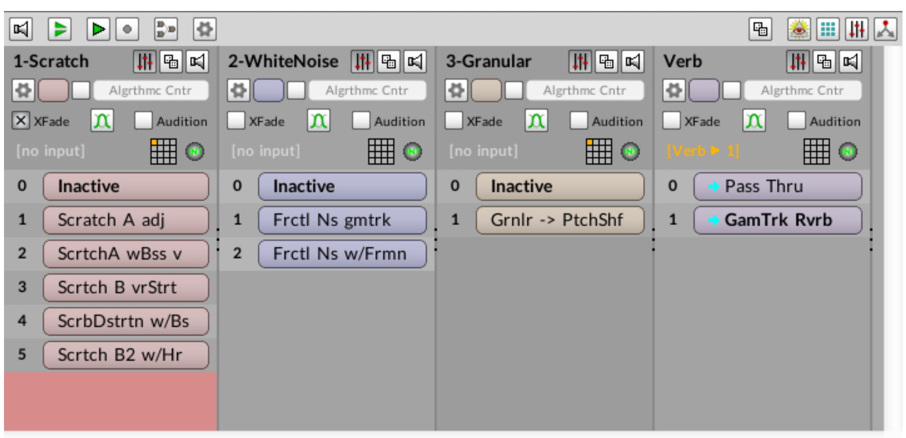


Figure 6-8: Multigrid layout of *SG6VS* (2017)

The primary physical control of the interface is the Z-axis of the Gametrak joystick, and in mapping, I revisited the distance sensor mapping design used in Waisvisz's The Hands, version 1 (Bellona 2017; Torre et al. 2016). The Z-axis measures distance between the hands, and the measurement controls overall output gain, an exponential control across all Distance-X works.

[4]Ableton, https://www.ableton.com/en/manual/session-view/#7-1-session-view-clips (accessed March 4, 2018).

The one-to-one correlation between hand distance and amplitude enhances my physical presence while expanding the parametric range tied to my physical body. Additionally, in the composition *SG6VS* (2017), the Z-axis is used to mimic The Hands "scratch" mode behavior (Video 6-6). An early example prototype may be heard in Audio 6-1, where 'NoteOn' messages and volume are tied to hand distance. (For discussion of "scratch" mode in relation to the parametric kinesphere, see Chapter 2.1.)

> Audio 6-1: Prototype of "scratch" mode on Distance-X. Copies of 'NoteOn' messages update at control rate, tethered to the Z-axis (hand distance) of the Gametrak. Z-axis also controls volume, EQ, and playback rate. The occasional clicking is due to voice-stealing without cross-fading.

Beyond gain control, other mappings are shared between compositions on Distance-X. For example, the time index of an audio file is typically mapped to Wiimote Roll with on/off of the scrub feature given to Wiimote B. If the scrub feature is implemented, Wiimote A then typically controls data zoom of the scrub parameter (see Section 3.1, Data Zoom). Additional Distance-X controls will be discussed below, relevant to their respective composition. All Distance-X software may be found in Appendix B.

6.3 Compositions

At the time of this writing, there are five works for Distance-X. Using these compositions, I developed a thirty-minute set for Distance-X, complete with original interim music. I composed interim music to fill technical breaks between the loading and launching of each composition software Multigrid (one may think of these breaks as similar to the function of Iannis Xenakis's *Concret PH* during the Brussels World's Fair (Holmes 2008, 340-1)). Each composition for Distance-X explores various sound-movements via a different set of mappings. Through basic software schemes and movement phrases, these compositions strive to maximize the overlap between creative sound and creative kinespheric space.

TCF4 (Study 1)

TCF4 (Study 1) investigates Distance-X as a choreographic controller through the establishment of basic sound-movement phrases (Video 6-3; Video 6-4). The first in the set of compositions, *TCF4 (Study 1)* focuses on the gain control of hand distance, vibrational scrubbing of an audio sample via the Wiimote's accelerometer, and basic parametric control of the XY joystick. The piece serves as a study of developing sonic phrases emerging from physical body movements and in pushing my ideas to the point of physical and aural exhaustion.

> Video 6-3: *TCF4 (Study 1)* (2017) for Distance-X. Performance at Virginia XChange concert, Virginia Tech, Blacksburg, VA, May 2, 2017.

> Video 6-4: *TCF4 (Study 1)* (2017) for Distance-X. Studio Documentation Video. Video shot and edited by Justin Michael Jeffers. http://JusInFocus.com

SG6VS

SG6VS investigates timbre through ordered presets, navigating between and through each of the different sonic spaces in the piece (Video 6-5; Video 6-6). The sound presets reside within a Multigrid in Kyma (Figure 6-8), which can be selected using Wii Remote -, Home, and + buttons. Some sounds and controls of *SG6VS* model the behavior of Michel Waisvisz's "scratch" mode from his first version of The Hands. (Chapter 2.1 and Chapter 3.6.2). In *SG6VS*, two controls effectively reconstruct MIDI 'NoteOn' messages, which characterize "scratch" mode (Torre et al. 2016). The Z-axis data stream of the Gametrak re-triggers an audio sample (Kyma's Sample Sound) at control rate, and Kyma's Replicator Sound generates polyphonic voice copies, complete with voice-stealing.

Voice-stealing is a digital polyphony concept—when the computer runs out of polyphonic voices to playback multiple sounds, the next additional sound 'steals' the oldest voice (very similar to a push/pop array). Voice-stealing is important to processing bandwidth and sonic character. Without the feature, added sound events would be ignored above the maximum number of voices. That is, unless a voice stops playing and makes a voice available, the computer may ignore any incoming messages for activating the next sound event. While Kyma easily handles polyphonic modulo voice control (Capytalk 6-1), one must additionally account for non-zero-crossing clicks and pops, which can be a result of stealing a voice mid-playback. Kyma's voice-stealing requires adding a full ramp (-1 to 1) for 10 ms, where there is a negative value for at least 5 ms, which removes any unwanted clicks and pops as a result of the voice-stealing behavior (Capytalk 6-2).[5]

```
((!Gate countTriggersMod:  ?NumberVoices) eq:
(?VoiceNumber - 1))
```
(Capytalk 6-1)

```
((!Gate countTriggersMod:  ?NumberVoices) eq:
(?VoiceNumber - 1)) fullRamp:  10 ms
```
(Capytalk 6-2)

Both Capytalk expressions incrementally step through the number of available voices and repeat the voice count once the total number of voices has been reached (i.e., modulo counter). If a voice equals a currently playing voice, the full ramp ensures a smooth voice-stealing transition.

Depending on how these voices are activated, programming the inclusion of audio copies can create distinct sonic fingerprints. For example, one method is to trigger voices simultaneously. Simultaneous triggering of voices, irrespective of voice number, will vertically stack the voices, and limit changes to any time-dependent parameter to the time of the trigger rate (e.g., ADSR). Figure 6-9 displays the simultaneous triggering of an audio parameter across seventeen voices. In Audio 6-2, seventeen voices control playback and frequency parameters, with all voices triggered simultaneously. The stacked succession of voices results in louder amplitudes and homophonic textures, and the synchronous update rate causes discrete changes in frequency.

[5] Jon Bellona and SSC, "Ensuring no clicks with Voice stealing," *Kyma Q&A*, May 1, 2017 http://kyma.symbolicsound.com/qa/2411/ensuring-no-clicks-with-voice-stealing?show=2411#q2411 (accessed February 3, 2018).

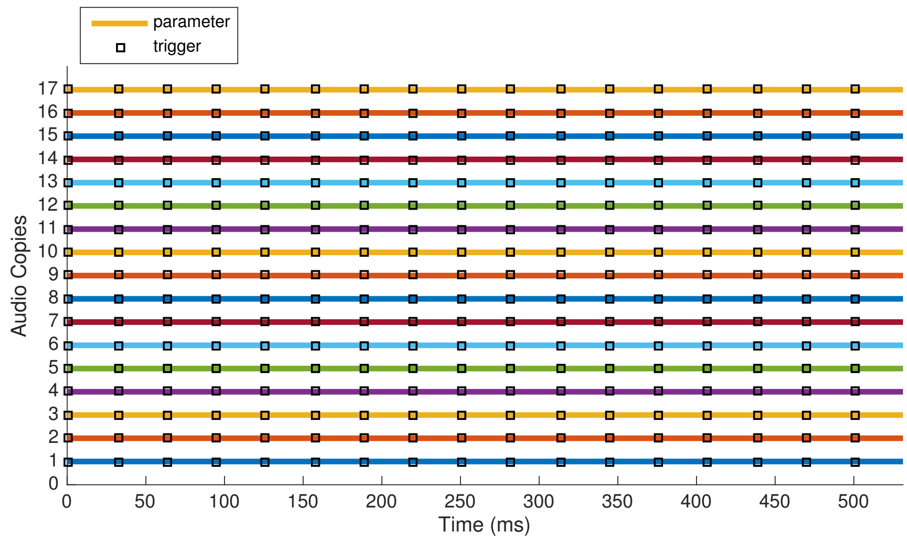


Figure 6-9: Synchronous triggering of seventeen copies of an audio parameter using the Capytalk expression, (!Param fullRamp: 10 ms), where !Param may be any audio parameter. The maximum amount of time for any parameter envelope is dependent upon the triggering or update rate (in this case 31.25 ms).

Audio 6-2: Seventeen copies of an audio sample with all copies triggering playback and updating frequency synchronously. The example was performed on Distance-X, where moving the left hand forward and back in the saggital plane controls frequency.

A second method is to sequentially trigger voices. By sequentially stepping through each voice for updating parameter values, the length of time it takes to trigger a parameter change increases by the number of voices available. Figure 6-10 displays how the sequential triggering of voices will offset the update of a voice's parameter, and allow for any envelope shape to unfold over a longer amount of time. Audio 6-3 demonstrates the sequential triggering of a frequency parameter. The voices still trigger simultaneously as before; there is only a staggered change in frequency. Audio 6-4 demonstrates sequential triggering of both voice and frequency.

Physical movements of Distance-X are choreographically the same between the three examples (Audio 6-2, Audio 6-3, and Audio 6-4). The arms move forward and back in the sagittal plane, twice slowly and twice again more quickly; yet, we can hear more of the audio waveform unfold in Audio 6-4 since playback events are triggered less often with the sequential voice gate. In this way, the sequential voice triggering may appear quieter, but the sound leaves spa-

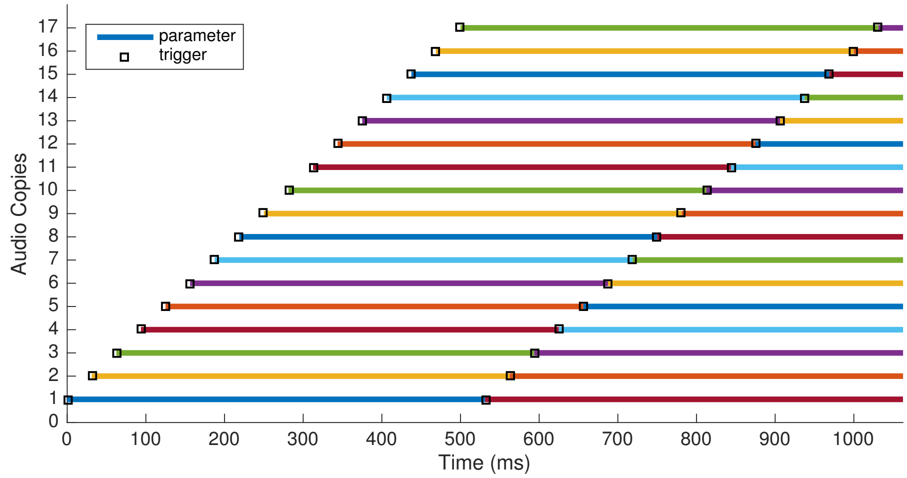


Figure 6-10: Sequential triggering of seventeen copies of an audio parameter using the Capytalk expression, [(((!Param countTriggersMod: ?NumberVoices) eq: (?VoiceNumber - 1)) fullRamp: 10 ms], where !Param may be any audio parameter variable. The parameter envelope duration is dependent upon the triggering rate multiplied by the number of audio copies (in this case, 31.25 ms * 17 voices = 531.25 ms).

tial traces of sound commensurate with the speed and position of the performer's hands. The faster and wider the movements, the clearer the delay, spectral shift, and panning.

In addition, all three examples (Audio 6-2, Audio 6-3, and Audio 6-4), update their audio parameters (and their copies) using the same rate, where the rate is equal to the Capytalk expression, 1 bpm: (!BPM * !Beats) smoothed. In all three examples, BPM equals 240 and !Beats is generally 8.0 (controlled by Y-axis and choreographically performed the same), such that each trigger pulse occurs at 1920 b.p.m., or every 31.25 ms.

Audio 6-3: Seventeen copies of an audio sample with all copies triggering playback synchronously. Each copy updates frequency sequentially (17 copies x 31.25 ms [control rate] = 531.25 ms [voice update rate]). In the example, moving the left hand forward and back in the saggital plane controls frequency with Distance-X.

Audio 6-4: Seventeen copies of an audio sample with sequential triggering of playback and frequency parameters. The longer update time per voice (17 copies x 31.25 ms [control rate] = 531.25 ms [voice update rate]) allows for more of the sample's waveform to be heard with the playback of each voice. In the example, moving the left hand forward and back in the saggital plane controls frequency with Distance-X.

Both the differences in the control rate and the number of voices will affect the overall update rate for voices. For example, when sequencing the triggering of audio playback for any number of voices, we allow up to (control rate * number of copies) of each audio sample to be played back (e.g., 531.25 ms in Audio 6-3 and Audio 6-4). Removing any voice and/or decreasing the control rate will shorten the playback time for each voice. When triggering is kept synchronous, only the control rate matters for controlling the update rate of voice parameters.

These simple alterations in how voices are triggered inside parameter space shifts how sounds develop over time. By sequentially updating voices within a number of parameters, sounds unfold more slowly due to the lengthened update rate of each voice. This programmatic byproduct leaves behind traces of sound that echo the pathways left by the performer's movements. With Distance-X, copies of sound are triggered at discrete locations in physical space, and if the performer moves faster and wider than the update rate, one can hear the fading echo of physical activity inside each voice. Thus, by adding multiple voices to sequentially control parameter space, we may augment the choreographic potential of controlling sound space. (For more on Physical Composition in performance, see Chapter 4.4, Performance Practice Values on Alternate Controllers.) The physical navigation between different sonic spaces is made possible by multiple voices controlling multiple parameters, and this process is explored within *SG6VS* (Video 6-5; Video 6-6).

Video 6-5: *SG6VS* (2017) for Distance-X. Performance at Twisted Branch Tea Bazaar, Charlottesville, VA, May 13, 2017.

Video 6-6: *SG6VS* (2017) for Distance-X. Studio Documentation Video. Video shot and edited by Justin Michael Jeffers. http://JusInFocus.com

Trump Is A Fascist

Trump Is A Fascist explores the mental state of the 45th President of the United States and those who shun him (Video 6-7; Video 6-8). By using explicit gestures that evoke a masturbatory act, the spoken words ejaculated from each gesture call out the President by name and sound out the frame through which he is viewed. The piece critiques the normalization of name-calling while embodying the narcissism and sexist behavior of President Trump.

Video 6-7: *Trump Is A Fascist* (2017) for Distance-X. Performance at Twisted Branch Tea Bazaar, Charlottesville, VA, May 13, 2017.

Video 6-8: *Trump Is A Fascist* (2017) for Distance-X. Studio Documentation Video. Video shot and edited by Justin Michael Jeffers. http://JusInFocus.com

Trump Is A Fascist, variation 2 revisits gestures within the first work to further explore and develop how the spoken sounds of "Trump is a fascist" might serve as a unified voice protesting the 45th President and his sympathetic treatment of white nationalists (Video 6-9). The adaptation is in response to Trump's remarks concerning a group of white nationalists who descended upon and terrorized Charlottesville, VA as part of a Unite the Right rally on August 11-12, 2017.

Video 6-9: *Trump Is A Fascist, variation 2* (2017) for Distance-X. Studio Documentation Video. Video shot and edited by Justin Michael Jeffers. http://JusInFocus.com

CDM v2

CDM v2 revisits an early-2015 fixed media work for dance (Figure 6-11; Audio 6-5) and late-2015 live performance work for Kyma, Gametrak, and Wacom tablet (Video 6-2). The 2017 revision remaps the Wacom controls onto the Wiimote interface of Distance-X, and the forearm interface removes any physical obstacles between the performer and audience (Video 6-10; Video 6-11). By maintaining the 2015 striking gesture that triggers audio samples, the piece maintains a continuity of performance and sonic imagery. *Convulse, Die, Mourn (CDM)* sonically explores three actions and reactions—convulsing (pain), dying (shock), and mourning (grief)—three actions in which we can lose control of our physical bodies, and reveal just how fragile we humans are.

Audio 6-5: Excerpt of *Convulse, Die, Mourn* (2015). Performed with seven male dancers at (sub)Urban Projections, Hult Center Lobby, Eugene, OR, April 2, 2015.

Figure 6-11: *Convulse, Die, Mourn* (2015), fixed media and dance. See Audio 6-5 for excerpt.

Video 6-10: *CDM v2* (2017) for Distance-X. Performance at Intel UX Innovations Summit, White Stag Building, Portland, OR, June 9, 2017. 

Video 6-11: *CDM v2* (2017) for Distance-X. Studio Documentation Video. Video shot and edited by Justin Michael Jeffers. http://JusInFocus.com 

HMW-mult3

HMW-mult3 investigates three-part voicing structures that are traversed using the 3-axis joystick of Distance-X (Video 6-12; Video 6-13). Each axis of the joystick controls a voice (e.g., root, third, fifth), and each voice has a collection of pitches that it may sound. By moving one's arms around one's body, sounded voices discretely move through their respective pitch collections, which harmonize together to form different chord and chord voicings (See Section 3.6.2, Multidimensional Arrays, for more on how this feature works).

Controls on the Wiimote help select different pitch collections, as well as cycle between two tracks of three-part voices. Wiimote Roll and Pitch control variables of tiny segments of audio samples, which drive wavetable synthesis (Roads 1996, 159-60). In Kyma, the Time-Alignment Utility (TAU) Sound calculates the wave shape and wavetable length based upon these Wiimote-dependent variables (time location, frequency, and formant variables to name a few), such that the length of both the wave shape and the wavetable dynamically update when any one of these variables shifts.

Since sample segments may be shifted and recaptured in real time, the three-part harmonies may be filtered and shaped timbrally on the fly. Multiple voices to each note bring additional dimension to the sound texture through subtle shifts in frequency and time (Audio 6-6; Figure 6-12).

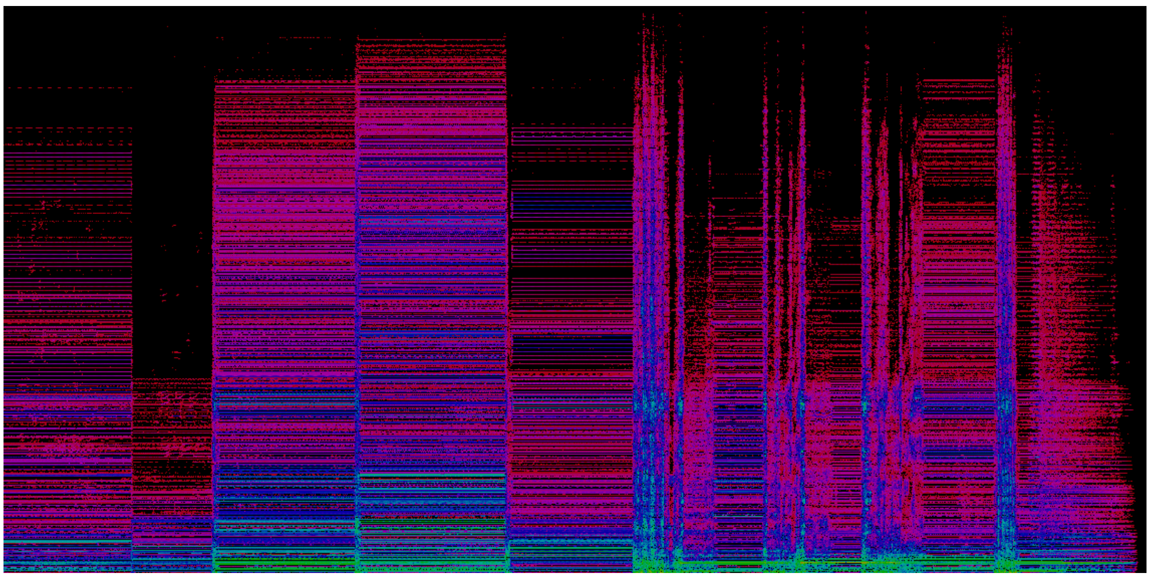


Figure 6-12: Spectral analysis of Audio 6-6. Shows how discrete changes to time location change the frequency spectrum of the wavetable synthesis, and how scrubbing time location, midway through the example, generates a noisier spectrum.

Video 6-12: *HMW-mult3* (2017) for Distance-X. Performance at Twisted Branch Tea Bazaar, Charlottesville, VA, May 13, 2017.

Video 6-13: *HMW-mult3* (2017) for Distance-X. Studio Documentation Video. Video shot and edited by Justin Michael Jeffers. http://JusInFocus.com

Audio 6-6: Three-part wavetable synthesis with changes to selections in time index of the audio sample. First 0:20 demonstrates discrete time location selections using the Wii Remote. The last 0:20 demonstrates scrubbing of time variable and freezing of time locations that create differences in timbre and amplitude (using Wii Roll and B button). A spectral analysis of the example is shown in Figure 6-12.

Interim Music

For live performance settings, I curated material to help fill the gaps between pieces due to software load and launch times. Examples include works from my spectral image series: *#Carbonfeed* (2016) and *Bhills* (2016), and a beat repeater mash-up: *Freedom/Feel It All* (2017).[6]

Audio 6-7: Spectral Image series, *Bhills* (2016)

Audio 6-8: Spectral Image series, *#Carbonfeed* (2016)

Audio 6-9: Beat Repeater Mash-up series, *Freedom / Feel It All* (2017)

Performances

A short list of performances of Distance-X include:

– *CDM v2* and *TCF4 (Study 1)* at Intel UX Innovations Summit, White Stag Building, Portland, OR, June 9, 2017

– Thirty-minute set of five pieces for Distance-X at Twisted Brach Tea Bazaar, Charlottesville, VA, May 13, 2017

– *TCF4 (Study 1)* at Virginia XChange concert, Virginia Tech, Blacksburg, VA, May 2, 2017

Distance-X and its associated works manifest my Physical Composition values (Chapter 5). The DMI (interface-software-sound) enables a way of working with body space and sound space that affords a personalized artistic practice. Distance-X assists me in making human-powered computer music. There are no tapes and no space-bar playback; there is only body movements turned musical mutants.

[6] Mash-up uses samples from Jurassic 5, *Freedom*, Power in Numbers, Interscope Records (CD), 2002; Feist, *I Feel It All*, The Reminder, Polydor Records (CD), 2007; and José González, *Heartbeats*, Veneer, Imperial Recordings (CD), 2003.

Chapter 7

Instrumental Extension: Data into Movement

> We all have lots of ready-made phrases and ideas, and the printer has ready-made sticks of letters, all sorted out into phrases. But if the printer wants to print something new—say, something in a new language, he will have to break up all that old sorting of the letters. In the same way, in order to think new thoughts or to say new things, we have to break up all our ready-made ideas and shuffle the pieces.
>
> Gregory Bateson (Bateson 1987, 16)

Throughout this dissertation, I have described how alternate controller DMIs and the body shape musical interactions. DMIs digitize information signals of the moving body, both inside (e.g., muscular tension, brain waves) and outside (e.g., motion, pressure). This body information serves as material for shaping and controlling music; but more importantly for composition, the physical body acts now as an *information* body.

This altered, moving body frames a different approach to digital music composition. Instead of thinking of physical body movements as the primary source of musical activity, we may treat the movement of information, the movement of data, as the source central to musical interactivity. We may reconfigure or shift our compositional frame to center on composing data movement, so that when we remove the gestural body as input, we keep the instrumental extension of its informational body (data) in focus. Data has already been used to activate mechanical motion in music (Kapur et al. 2010; P. Mathews et al. 2014), for sonification (Scaletti and Craig 1991) and in algorithmic composition (Cope 2000). Even if we ignore the physical connectivity of informational bodies, crafting a human-made digital system (a DMI or a digital composition) has two implications for a digital music practice. One, filtered data is not objective. The filtration of the body signal or any activity signal saves fingerprints of its creator(s). Two, the movement of data can substitute for the movement of the body. The human body is no longer necessary to control musical systems.

With the first implication, that **filtered data is not objective**, we must question how data is quantitatively *given* to us. Human choices occur in the sorting and ordering of data. For example, with constructing a DMI, we make choices about what to listen to. The numerical values that represent the body's actions and movements account for only a small portion of all bodily actions and movements. If deciding what to listen for is still a choice (e.g., if one creates the instrument of measurement), one must still make choices in the treatment and sounding of that data. With DMIs, choices in software, technique, and composition constitute the mapping process. All our data is *cooked*, as Bateson explains,

> Always there is a transformation or recoding of the raw event which intervenes between.... The human voice is transformed into variable magnetizations of tape. Moreover, always and inevitably, there is a selection of data because the total universe, past and present, is not subject to observation from any given observer's position.... In a strict sense, therefore, no data are truly 'raw,' and every record has been somehow subjected to editing and transformation either by man or by his instruments (Bateson 1987, xviii).

We use data to construct digital compositions out of bodies and movements, but data is not "before the fact" (Gitelman 2013, 2). Data lives in the world as an entity created by the human and her technology. Data constitutes a body, and like all bodies, they are prone to biases and "marks" (Weiss 1999, 2-3). Data are situated within biological, ecological, phenomenological, cultural, and social arenas (Johnson 2007). The choices around data, then, contain the potential to impact the composition as much as the sounds themselves.

The second implication of digital systems reveals that **the movement of data can substitute for the movement of a performing body** to control musical systems. In a digital system, the instrumental extension of musical bodies no longer needs to be corporeal. Instead of data movement as extension of a performing body, moving data may sample other non-musical objects and activities. The musical potential of data resides in the flow of the information and the sonic presentation of the data in question.

Composers have long used rules to guide their writing, and the digital age offers another opportunity to formulate rules and methods for driving musical systems. For example, a composer may create a set of *rules* (read mappings) for a single work, as with the case with John Luther Adams' *The Place Where You Go To Listen* (2007). Other composers may enact prescriptive methods, as with R. Luke DuBois' *Billboard I* (2006) and Brian House's *Quotidian Record* (2012) (Video 7-1) (Dubois 2006; House 2012). Other musical protocols involving data can extend to a set of works, like in Gordon Mumma's *Mograph* series (1962-4). A single data framework may even offer its rich content as a source for multiple musical interpretations and rule-based systems, as is the case with Twitter in *TweetDreams* (Dahl et al. 2011), *Literally Speaking* (Posselt and Luge 2011), *#Carbonfeed* (Bellona and Park 2014), and *MMODM* (Tome et al. 2015). These last few works utilize Twitter's application programming interface (API) to serve different musical systems.

Video 7-1: *Quotidian Record* (2012) by Brian House turns "habitual patterns" into an "alternative to the narratives of... corporate data infrastructure" (House 2012).

Data does not *tell* us anything about phrases of movement or what the movement means. Instead, these movements are pointed out, identified as patterns by someone or something. The procedure of identifying the movement in data is "something like a sieve, a threshold, or, *par excellence*, a sense organ" (Bateson 1987, xxiv). In digital music, our "sense organ" includes listening and computer programming. In order to create data, choices are made about what information is filtered and what information is highlighted. In Physical Composition, these choices also include the human performer.

Even as we remove the body from the signal, we still maintain a digital trace of its human counterpart to a varying degree. When we replace the human in the creation of structure, as with Artificial Intelligence (AI), we shift the human one more place toward the outside of the act; however, the human creator of AI is still responsible for setting a body in motion. That is, the removal of the physical body in digital music does not remove the body of the composer, the creator of the system, who pulls on the strings of its data-body marionette.

The practice of filtration and highlighting information can be heard inside Villa-Lobos' *New*

York Skyline Melody (1939), a composition that uses *millimetrization*, a mathematical process of assigning outlines with a graphical grid to pitch content, from the Schillinger System of Music Composition (Bianchi and Manzo 2016, xxv) (Audio 7-1).[1] The strict graphical 2D representation of the NYC skyline identifies pitch content; however, the sonic outcome flows outward as a saccharine reflection of its quantifiable input, a creative offering to a mathematical process. Still, the use of quantification, perception, and boundaries informs a musical practice, "a matter of sorting and dividing" (Bateson 1987, xxiv). These processes rewire human-shaped information into a human-shaped narrative, whether or not composers are interested in unveiling the source and implications of their data. Perhaps that is the power of digital music in transforming information into sonic activity. "Movement is... a way to act out body-image affect" (Freedman 1990, 286).

Audio 7-1: Heitor Villa-Lobos, *New York Skyline Melody* (1939)

Movement remains part of data-driven systems regardless of the source of the data and the appearance of a physical body. Whether through the eerie silence of inactivity equating to human life in Rachel Trapp's *Overmorrow* (2014) (Trapp 2014), the literal recordings of our world in Alvin Lucier's *Sferics* (1981) (Lucier 2009), the mechanical tapping of computer-controlled shoes seen in Peter William Holden's *SoleNoid* β (2009) (Video 7-2), or activity schedules inverted into a string instrument with Alexander Chen's *Conductor* (2011) (Video 7-3), data drives sounds that signal a direct link between an instrumental other and our moved experience (Sutil 2015, 42). In digital music, the movement of data can be understood through sounded movement.

Video 7-2: *SoleNoid* β (2009) by Peter William Holden uses software to control the mechanic motion of eight tap-dancing shoes, which rhythmically tap out a composition by Marko Wild (Holden 2009).

Video 7-3: *Conductor* (2011) by Alexander Chen uses the NYC subway train schedule to transform the metro map into a string instrument (Chen 2011).

[1]Performance by Alfred Heller, Heitor Villa-Lobos, Piano Works, Et'Cetera, 2004.

In my explication of Physical Composition, I have attempted to reveal how movement acts as a "carrier to thought" (Sutil 2015, 235), and how the active use of the body reinforces transmission. By decoupling body and data in digital music, we shift the carrier signal from body movement to the movement of information of any type. This shift does not undercut Physical Composition, but rather reinforces the importance of movement in our musical systems. To help outline how the shift from first-order to second-order movement data sounds, the next section details two data-driven works, *#Carbonfeed* (2014) and *Aqua•litative* (2016).

7.1 Data Movement Musical Works

The following musical works, *#Carbonfeed* (2014) and *Aqua•litative* (2016), depict music made using second-order movement data. *#Carbonfeed* channels real-time interactions on Twitter, where Twitter users around the world collectively sound out an electronic composition in a gallery space.[2] *Aqua•litative* (2016) slowly unfolds moving patterns of rainfall and temperature over forty years of weather station data along a nineteen-foot structure. Where the physical sounding out of these systems may be near impossible given the density of all tweets or the span of historical time, we may instead leverage digital technologies to transform prodigious quantities or lengthy time-scales into a human-scaled experience.

#Carbonfeed (2014)

With the advent of social media like Facebook, Twitter, and Instagram, humans have increased their production of digital content (Terdiman 2012). Even simple online interactions generate carbon emissions; a Google search has been estimated to generate 0.2 grams of CO_2 (Hölzle 2009). To keep pace with growing online media, there is an increasing dependence upon data

[2]#Carbonfeed is by Jon Bellona and John Park, with contributions by David Bellona. The project was made possible through an OpenGrounds Art & Environmental Action Scholarship, funded by the Jefferson Trust. http://carbonfeed.org (accessed April 19, 2018).

centers,[3] which now account for two-percent of the United States electricity consumption.[4] #CarbonFeed directly challenges the popular notion that virtuality is disconnected from reality. Through sonifying Twitter feeds and correlating individual tweets with physical, ephemeral traces of air released into water, the work reveals the environmental cost of online behavior and its supportive physical infrastructure (Video 7-4). Users can participate and implicate themselves by tweeting #carbonfeed or any one of the hashtags appearing on the front of the six LCD screens (Figure 7-1).

Video 7-4: #Carbonfeed: The Weight of Digital Behavior

Figure 7-1: *#Carbonfeed* (2014)

[3]Rich Miller, "How Many Data Centers? Emerson Says 500,000," *Data Center Knowledge*, December 14, 2011. http://www.datacenterknowledge.com/archives/2011/12/14/how-many-data-centers-emerson-says-500000/ (accessed December 24, 2017)

[4]John Markoff, "Data Centers' Power Use Less Than Was Expected," *New York Times*, July 31, 2011. http://www.nytimes.com/2011/08/01/technology/data-centers-using-less-power-than-forecast-report-says.html (accessed January 4, 2018)

The installation rests on a four-foot-by-eight-foot melamine tabletop supported by three trestles. There are six tubes filled with water, each connected to a solenoid valve and attached to an ultra-quiet air compressor resting nearby. #Carbonfeed works by mapping tweets from Twitter users around the world in real time. Based on a customizable set of hashtags running on *node.js*,[5] the work listens for specific tweets. Each incoming tweet is sent from node.js to Max/MSP and Processing via Open Sound Control (OSC) messages. Max/MSP translates the content of these OSC messages (tweet length, location, language of tweet, etc.) into digital sound synthesis, generating a real-time sonic composition. Digital sound is output from the computer to a power amplifier that also rests underneath the table. The corresponding OSC message received by Processing re-transmits its data as a Serial message out the USB port to an Arduino Uno, which triggers the opening/closing of one of the six solenoid valves. The compressed air generates a small air bubble, synchronously manifesting a physical and ephemeral by-product of each tweet.

Aqua•litative (2016)

Aqua•litative (2016) is an installation that renders multiple data sets of California's water history into a physical experience.[6] The work takes forty-years of weather station data across twenty-six locations in the state, and transforms each weather station's data into a physical form. *Aqua•litative* spans nineteen feet in length and holds twenty-six modules, with each module containing its own servo motor, clock chime, and solenoid. A covered box in the middle of the installation at the floor houses the main electronics. The twenty-six clock chimes are cut at different lengths, forming an array of pitched material. To activate the chimes, an Arduino sends an electrical impulse out to an electrical relay, which moves a solenoid that 'pings' its respective chime. Two Arduinos (Uno and Mega respectively) serve the electrical components—one board controls the twenty-six servo motors and a second board controls the solenoids/chimes. The separation of components onto two boards better serves the musical timing for each system.

[5]node.js, https://nodejs.org/en/ (accessed February 16, 2018).

[6]Aqua•litative is by Jon Bellona and John Park, with code parsing software built by John Reagan. The work was funded in part by the Jefferson Trust and the University of Virginia Office of Graduate and Postdoctoral Affairs. http://aqualitative.org (accessed April 19, 2018).

Aqua•litative redux (2016)

Aqua•litative redux (2016) revisits the early-2016 kinetic installation by navigating sound and movement through the syntactical construction of code. The work actively performs seven musical works created from numeric data patterns. In the age of algorithms, artificial intelligence and pervasive data-mining, *Aqua•litative redux* aims to sonify and visualize the invisible digital architecture that increasingly affects our lives. Here, the redux version models structures in the virtual world and translates them into kinetic movement and acoustic sound, evoking the patterns of the weather station data in a more playful, compositional endeavor. Twenty-six modules, each containing a servo motor and solenoid relay, are driven by custom software. The software cycles through basic blocks of logic, constructing emergent sonic patterns in a continuously evolving play between density and rhythm. Movement flows as collapsing waves, additively striking a cybernetic balance between natural order and machinic motion. *Aqua•litative redux* is simultaneously data driven and autonomous, a human construction forming its own logic.

The twenty-six clock chimes rotate through seven musical works, each contained within their own section of code on the Arduino board (Video 7-5 documents one of these works). The twenty-six servo motors move according to physical models of wave patterns. Two waves span out across the length of the installation, folding over onto each other in a display of constructive and destructive interference. The overlapping waves mimic patterns found in the natural environment (Figure 7-2 and Figure 7-3). *Aqua•litative redux* continuously spins on its own, looping endlessly until power is cycled.

Video 7-5: *Aqua•litative: Precipitation 3* (2016) at Duke Gallery, Harrisonburg, VA

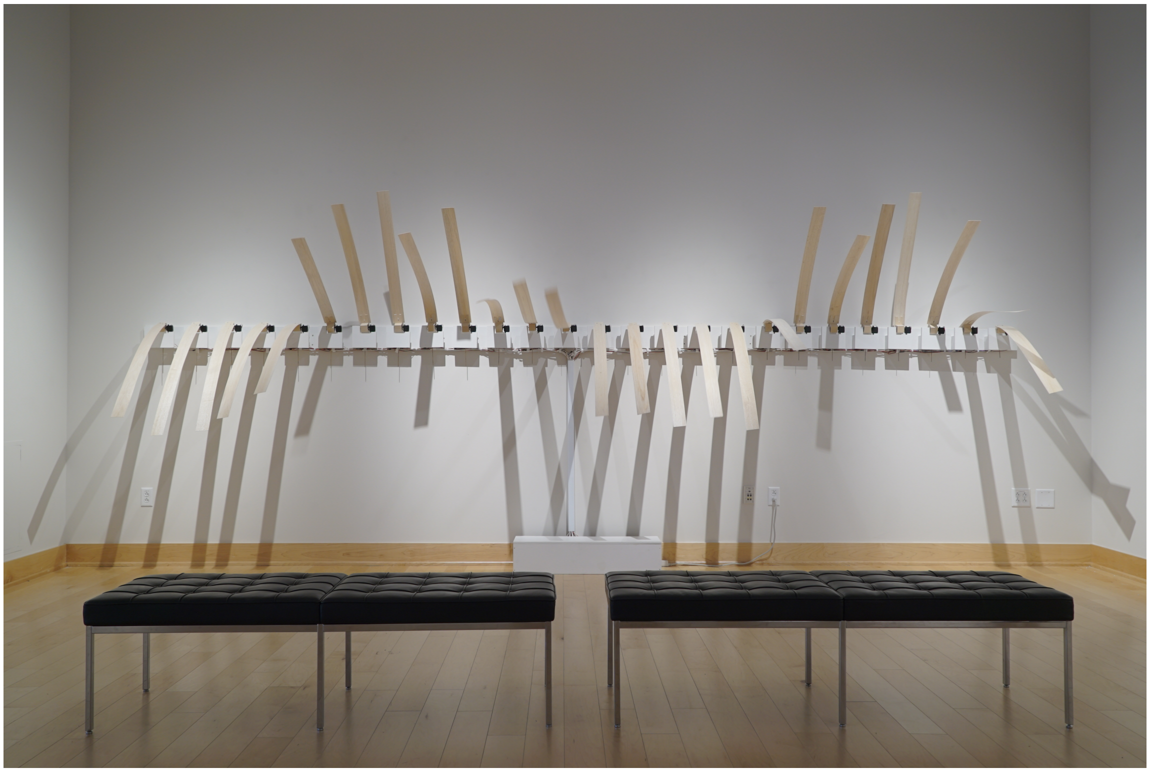


Figure 7-2: *Aqua•litative redux* (2016) at Duke Gallery, Harrisonburg, VA

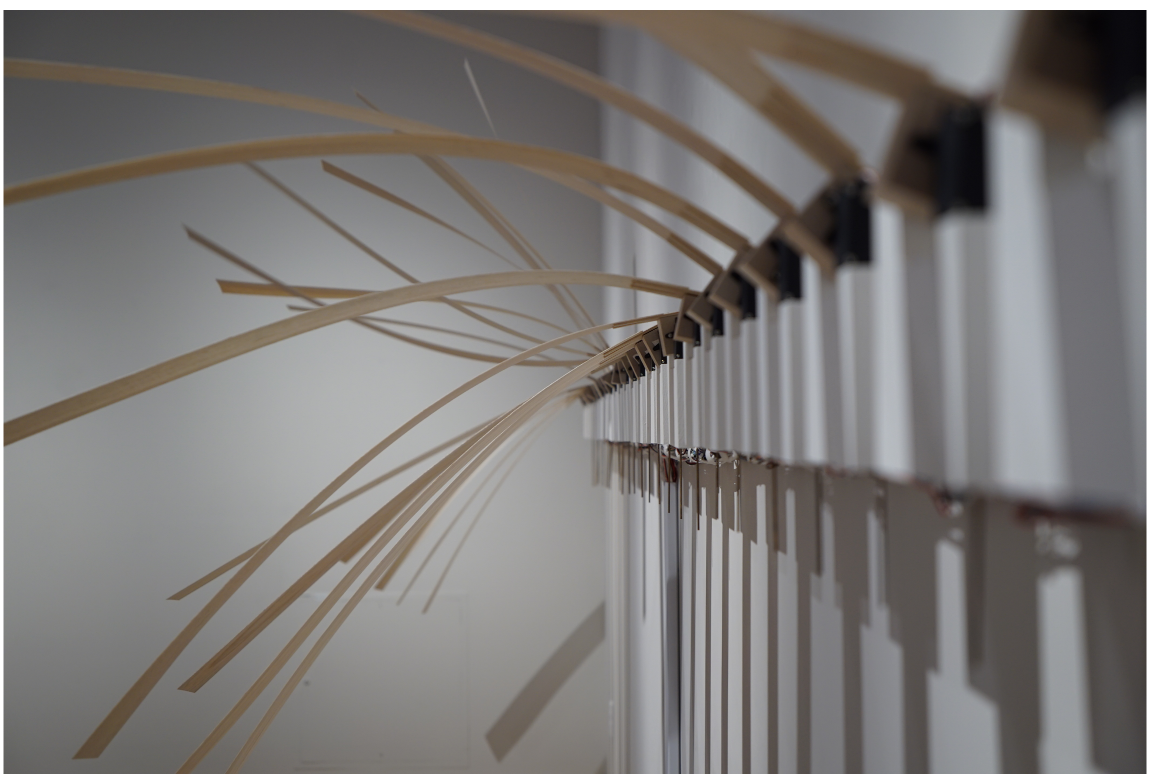


Figure 7-3: *Aqua•litative redux* (2016) at Duke Gallery, Harrisonburg, VA

Conclusion

In recruiting moving bodies to act inside digital systems, where physicality is a choice but not a requirement, we must carefully consider how the performer fits in. Physical Composition seeks to address the concerns and the capacities of these bodies, even when the sonic practice calls for little to no movement, or movement from a non-human source. And where digital composition does include moving human bodies, a space where human activity is paramount, Physical Composition endeavors to stand as a model for achieving symbiosis between performer and digital sound.

Today, as we continue to face issues of digital inclusion, net neutrality, open innovation, and systems intelligence, an embrace of physical bodies inside our digital lens can help acknowledge the complex and diverse stories that make-up our musical communities. Physical Composition is about bodies, but more specifically Physical Composition is about *moving* bodies, a real-time and dynamic interaction with others that plays out within an envelope of sound. Indeed, we shape and are shaped by digital technologies, and Physical Composition moves us to remember that our musical activities, digital as they may be, for now, remain tethered to our moving selves and our moving partners.

Appendix A

Compositions

Table A.1: Digital Musical Instrument Compositions

Title	Year	DMI[1]	Interface	Basic Mapping	Sound Synthesis
TCF4 (Study 1)	2017	Distance-X	Gametrak hack, Wiimote	Multigrid	Kyma
Trump is a Fascist v2	2017	Distance-X	Gametrak hack, Wiimote	Multigrid	Kyma
Trump is a Fascist	2017	Distance-X	Gametrak hack, Wiimote	Multigrid	Kyma
SG6VS	2017	Distance-X	Gametrak hack, Wiimote	Multigrid	Kyma
CDM-v2	2017	Distance-X	Gametrak hack, Wiimote	Trigger & TimeIndex	Kyma
HMW-mult3	2017	Distance-X	Gametrak hack, Wiimote	TAU	Kyma
Immaterial Vamp	2017	Open Instrumentation	varies	varies	varies
MG-2	2017	OBOF	custom	one button, one fader	Kyma
Torch	2016	n/a	Two PS controllers	Trigger & Joystick	Ableton
CDM	2015	n/a	Gametrak, Wacom	Trigger & TimeIndex	Kyma
HMW	2015	n/a	Wacom	TAU	Kyma
triAngulation	2014	n/a	Voice and triAngulator	Pitch shift, trio patch	Max/MSP
Smooch	2014	n/a	Wacom	TAU	Kyma
AUU (And Uh Um)	2014	n/a	eMotion	Kyma Timeline	Kyma
Great Speeches	2013	n/a	Qwerty keys	Control-Rate Storage	Max/MSP
The Beat (Nathan Asman)	2013	n/a	Kinect	MIDI CC between hands	Ableton
Casting	2013	n/a	Kinect	Threshold Triggers	Kyma
Sound Pong	2012	n/a	Four Wiimotes	Button triggers, Accel	Kyma
Running Expressions	2011	Runner	Heart-rate monitor, Wiimotes, Jeenode wireless	various	Kyma
AUU (And Uh Um)	2010	n/a	Wacom	Kyma Timeline	Kyma

[1]DMI column provides the Digital Musical Instrument name, if applicable. Additional columns (Interface, Basic Mapping, and Sound Synthesis) provide details about DMI components.

Appendix B

Software

All software is included as supplemental files to the dissertation. URLs are included in table below for enabling online access.

Table B.1: Digital Musical Instrument Open-Source Software

Title	**Year**	**Language**	**Type**	**Version**	**URL**
Distance-X	2017	Kyma	Various	1.0.0	http://dx.doi.org/10.18130/V3/DQQZOG
Expression Toolkit[1]	2017	Kyma	Prototypes	1.0.0	http://dx.doi.org/10.18130/V3/OPUUGY
(OBOF) One Button One Fader	2017	Various	Various	1.0.0	http://dx.doi.org/10.18130/V3/OPUUGY[2]
data.*	2017	Max/MSP	Package	1.0.0	https://github.com/jpbellona/data-max-package
Beat Repeat	2017	Kyma	Sound	1.0	https://kyma.symbolicsound.com/library/beat-repeat/
recall-shift	2015	Max/MSP	Package	1.0.0	https://github.com/jpbellona/recall-shift
mixer.*	2015	Max/MSP	Package	0.0.3	https://github.com/jpbellona/mixer-max-package
korg.nano	2015	Max/MSP	Package	0.0.1	http://jpbellona.com/work/korg-nano-max-package/
jpb.mod.*	2014	Max/MSP	Package	0.0.7	http://jpbellona.com/work/jpb-mod/
simpleKinect	2013	Processing	Source	1.1	https://github.com/jpbellona/simpleKinect
Kinect-Via-	2011-2	Max/MSP	Abstraction	1.2.1	http://jpbellona.com/work/kinect-via-interface-series/
Wiimote Controllers	2011	Max/MSP	Abstraction	1.0.0	http://jpbellona.com/work/wiimote-controllers/

[1]Expression Toolkit includes Kyma Prototypes for Wacom, Wiimote, Gametrak, and Distance-X as well as Custom Classes (i.e., Data Zoom) and Sounds for working with rhythm, CSV files, scripts, and other concepts.
[2]OBOF software included in the online Expression Toolkit .zip on University of Virginia's Dataverse (LibraData).

Appendix C

Scores

AUU
(And Uh Um)

Wacom tablet
and Kyma
(2 to 8 channels)

by Jon Bellona

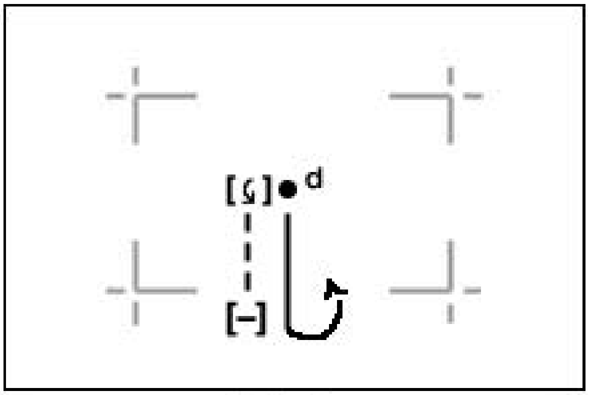
Legend

[↶]	Tilt Wacom pen towards you
[–]	Wacom pen is vertical, tilt normal
[↷]	Tilt Wacom pen away from you
¦	Interpolate between Wacom pen tilt markings
rit.	Musical ritardando
● u	Lift Wacom pen up off the tablet
● d	Put Wacom pen down on tablet
PB1	Pen button 1
PB2	Pen button 2

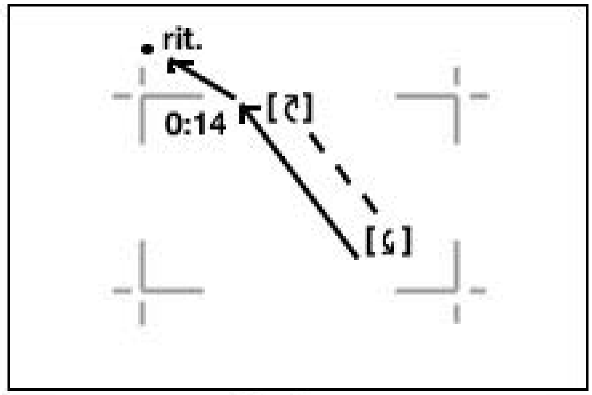
AUU (And Uh Um)

by Jon Bellona

SECTION 1



Adagio



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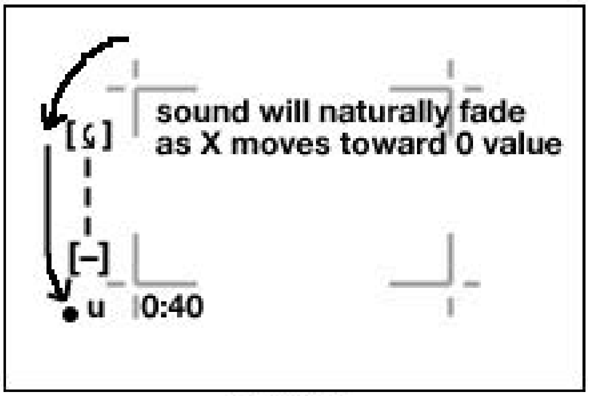
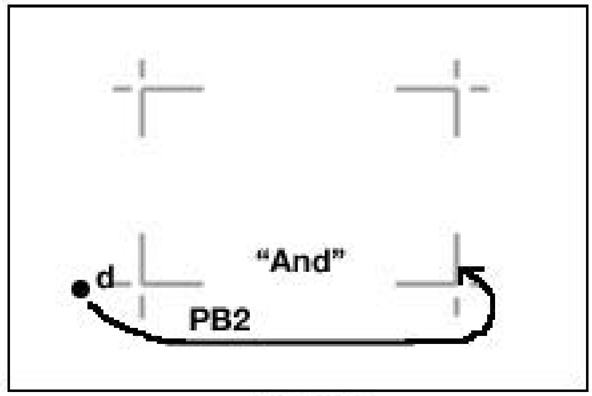
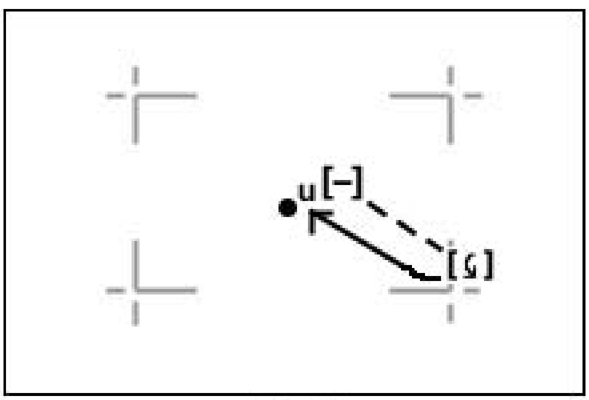


Adagio

–breathe–

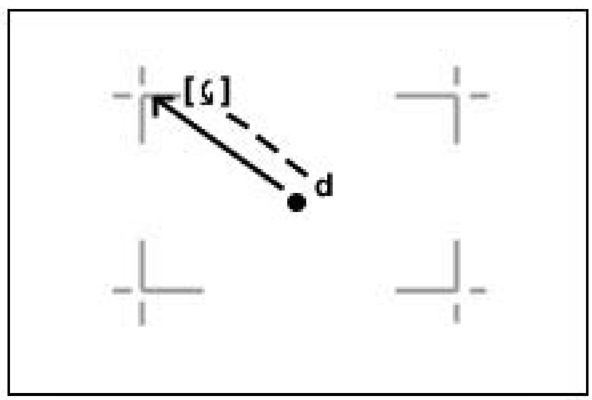


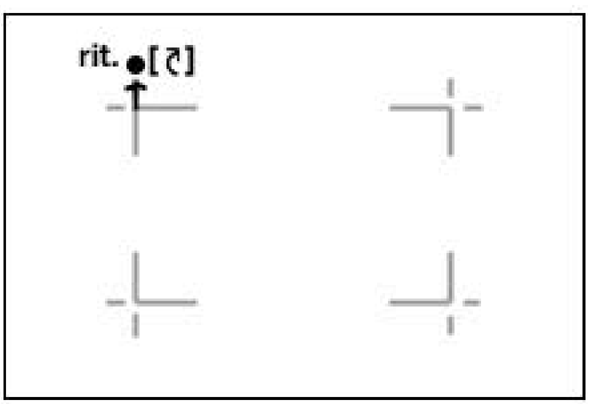
Allegro



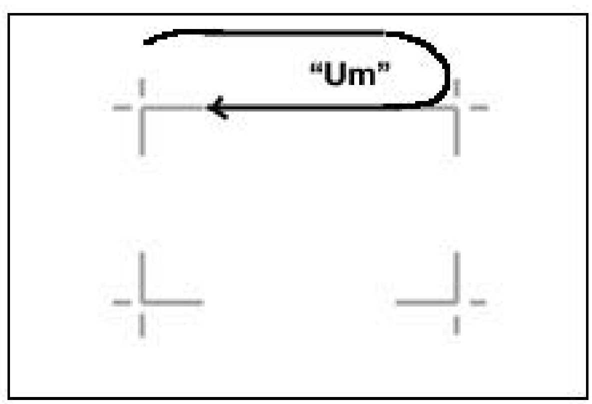
Adagio

–breathe–

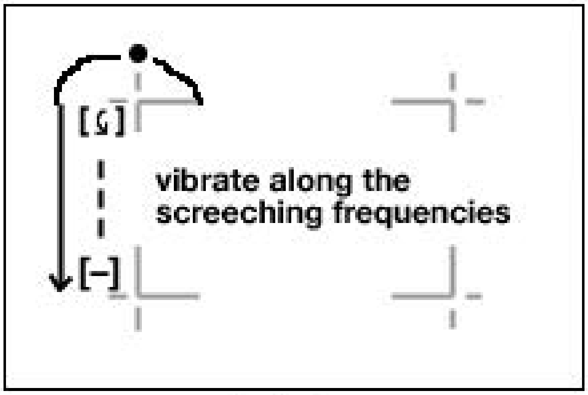




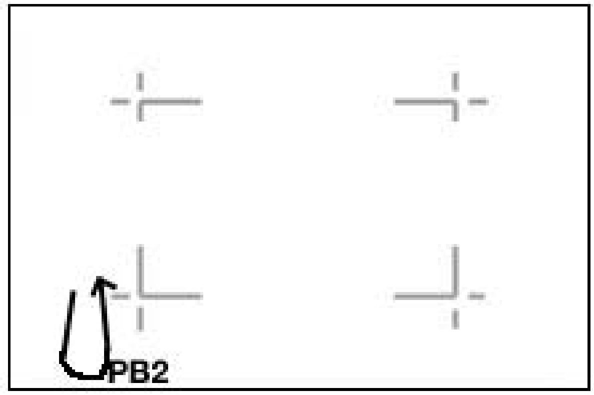
Lento



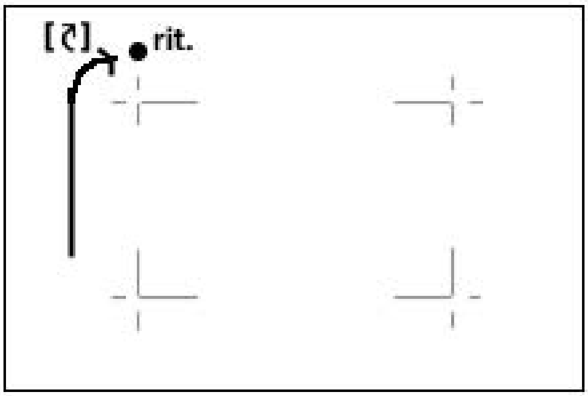
Allegro



Adagio



Allegro con Presto



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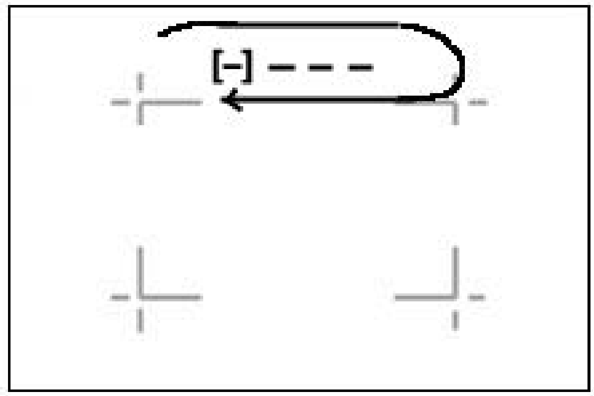

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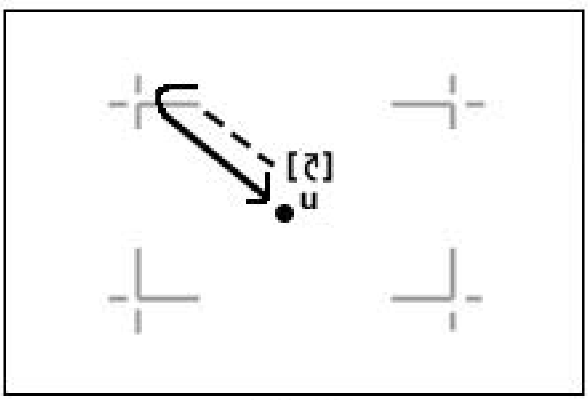
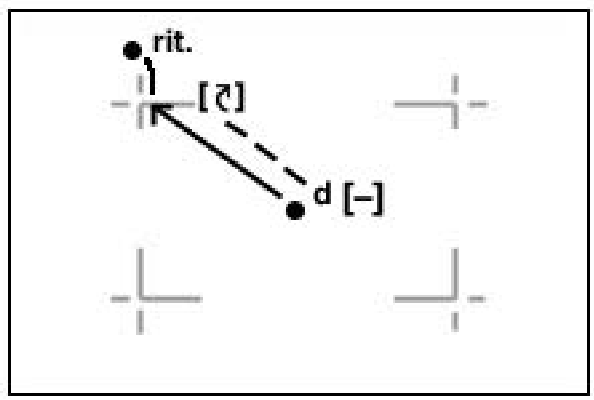
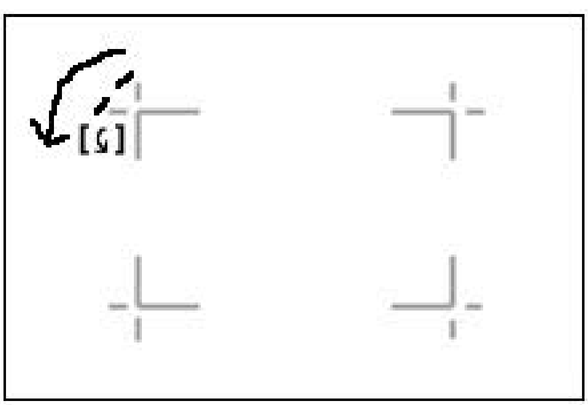


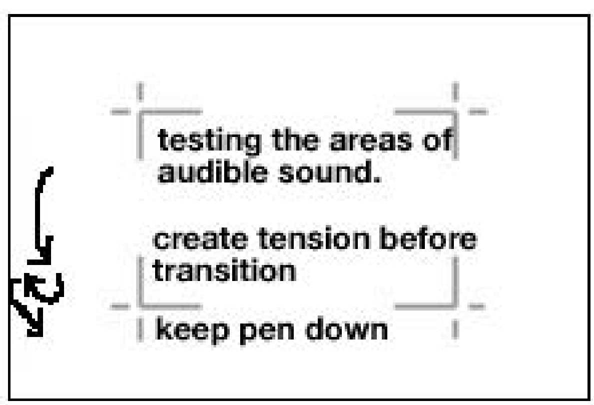
Adagio

–breathe–





Lento



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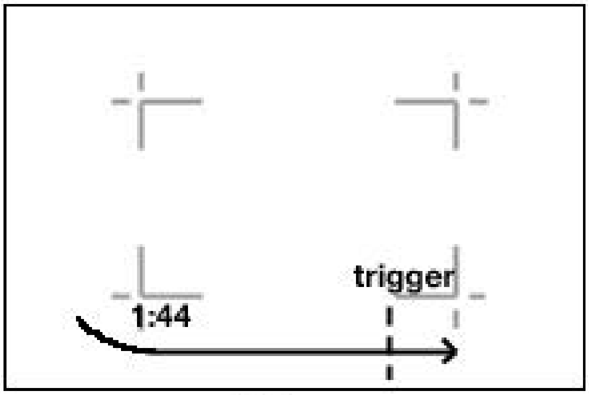

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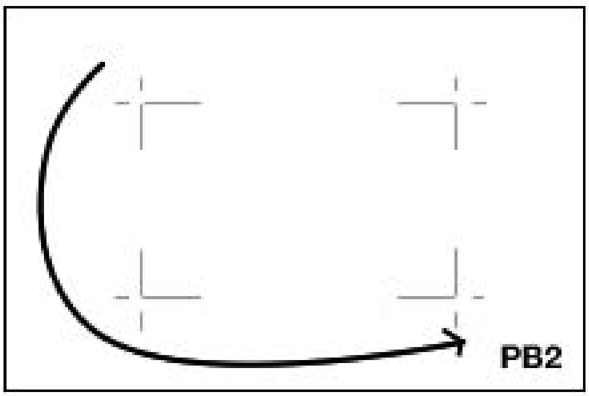
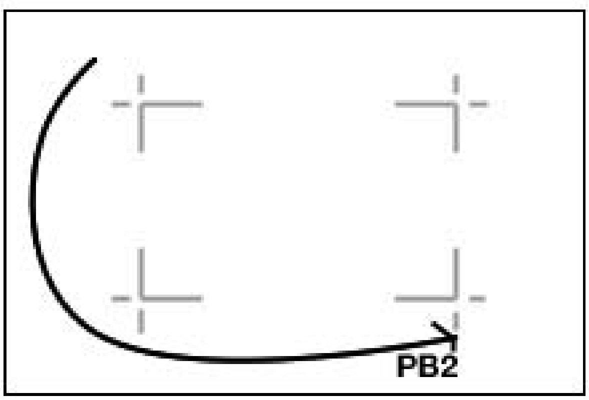
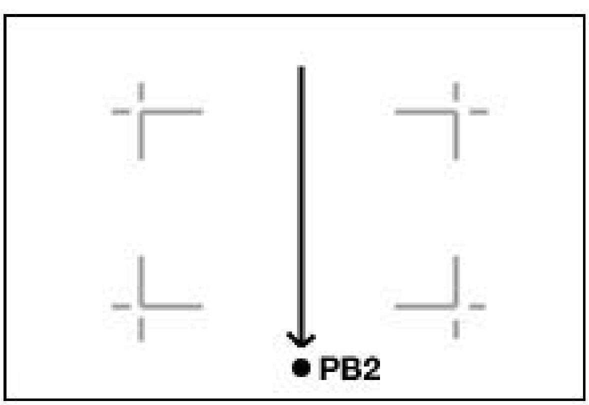
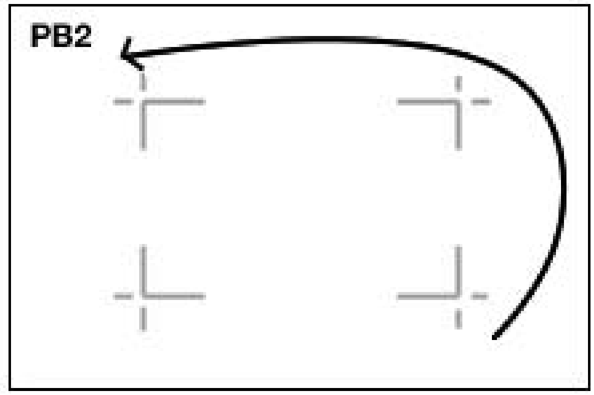




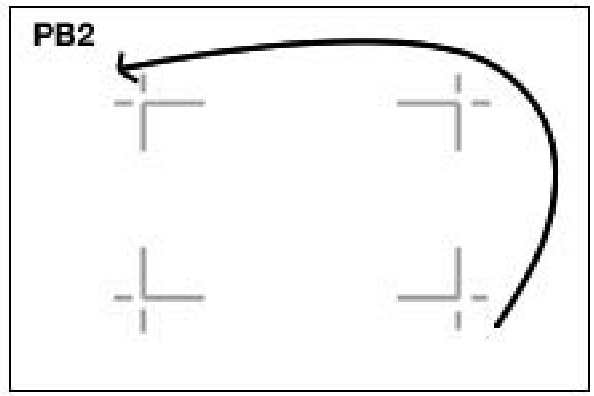


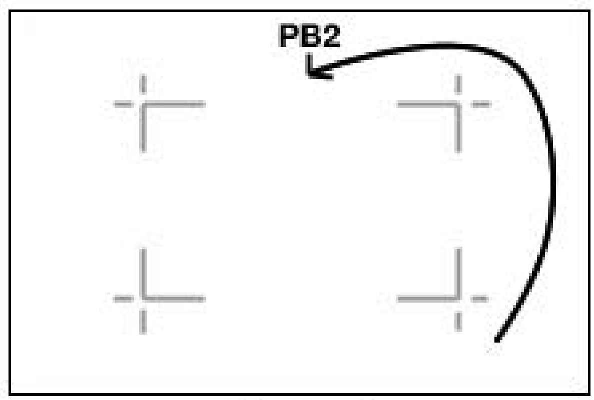
Allegro

SECTION 2



con Presto





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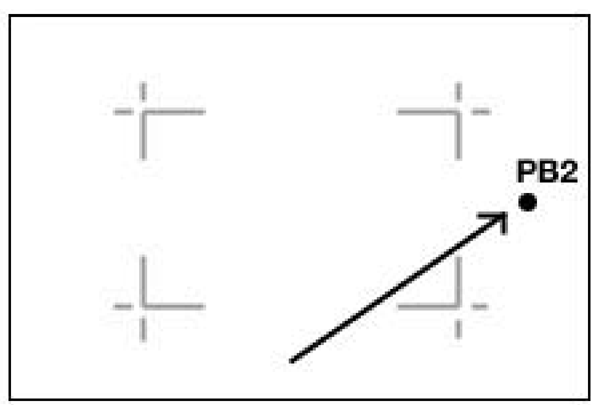
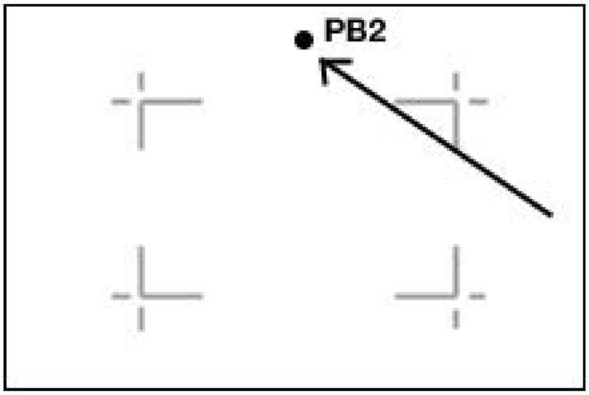
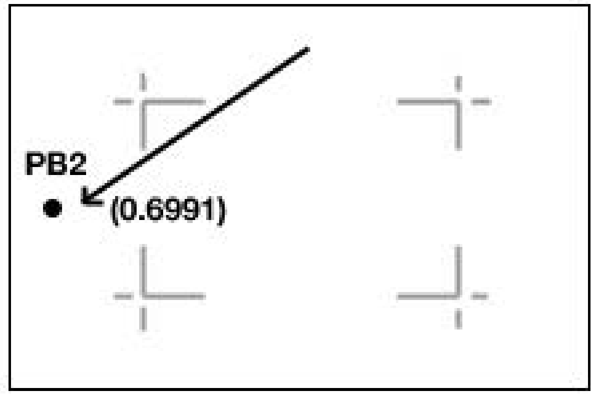
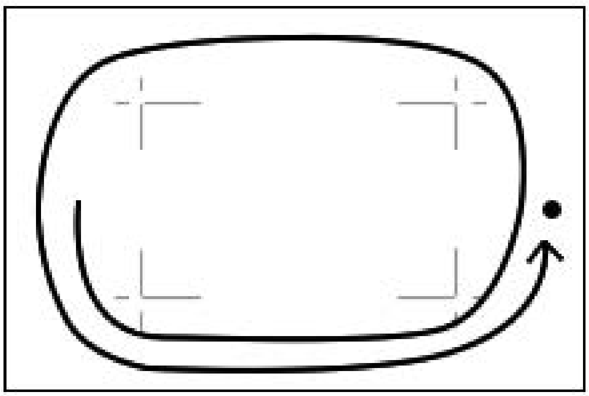
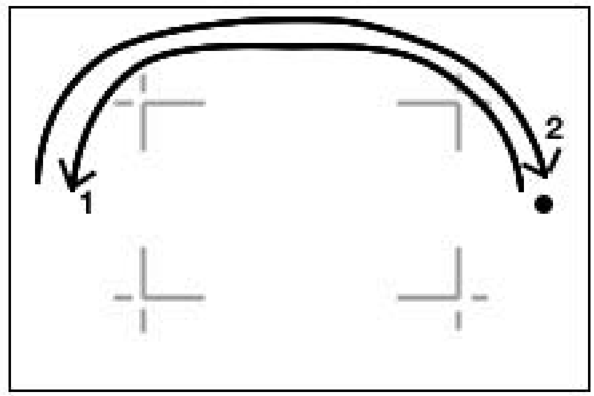


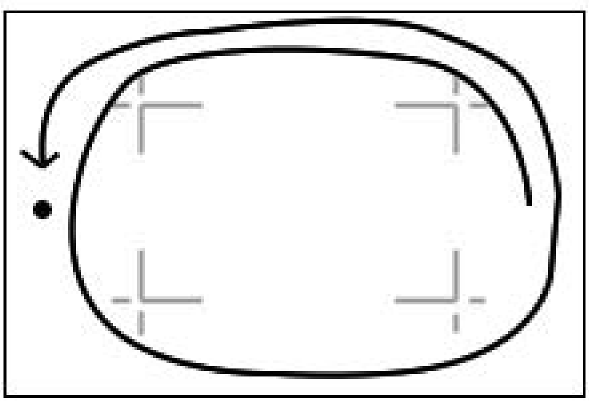
Holds in section 2 are for a few seconds, long and not stagnant. Move the pen in very small circles.

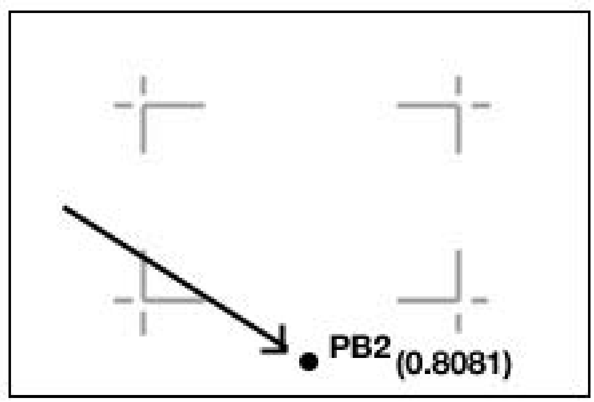

PB2

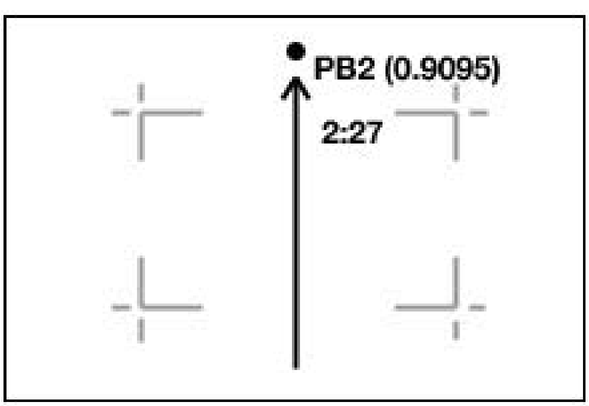

PB2
(0.6991)



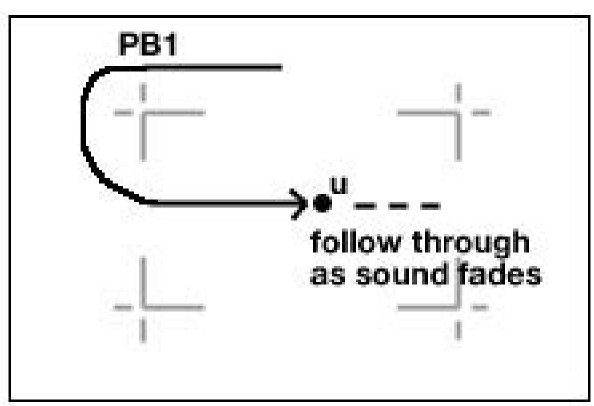

2
1



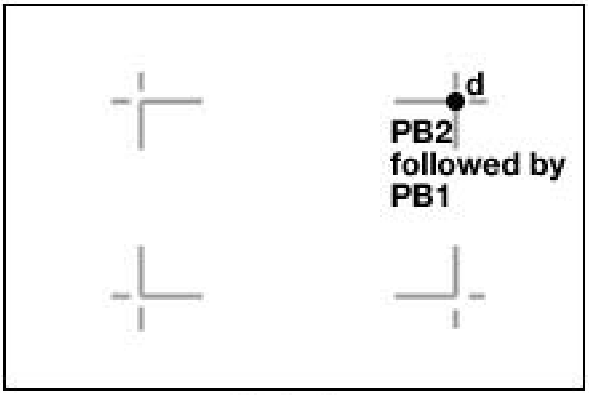

PB2
(0.8081)


PB2 (0.9095)
2:27

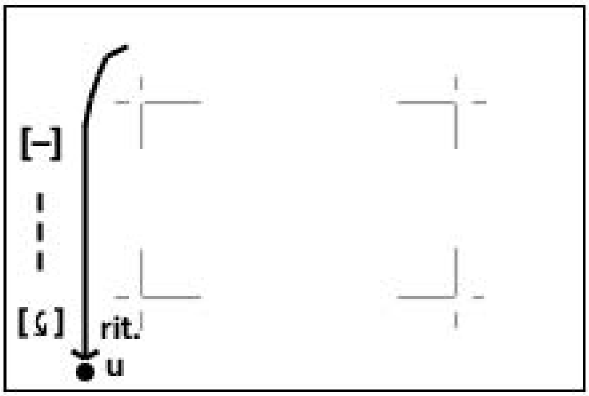
Lento


PB1
u
follow through
as sound fades

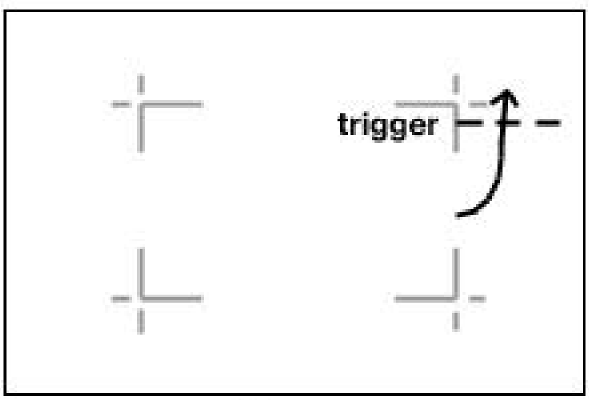
SECTION 3



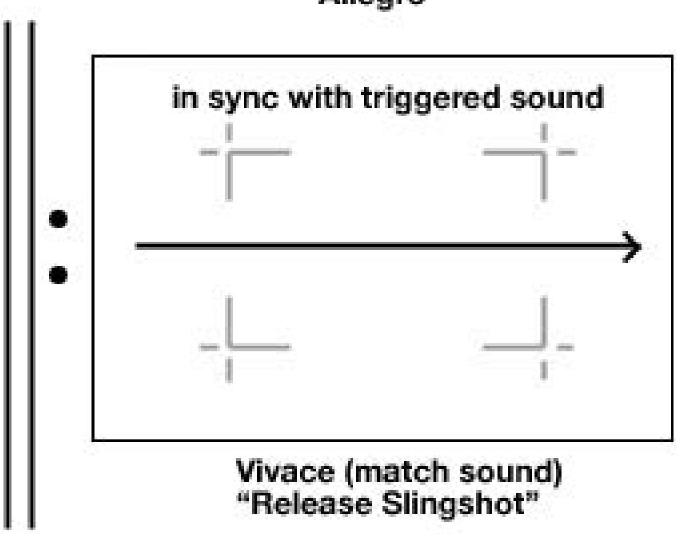
Adagio



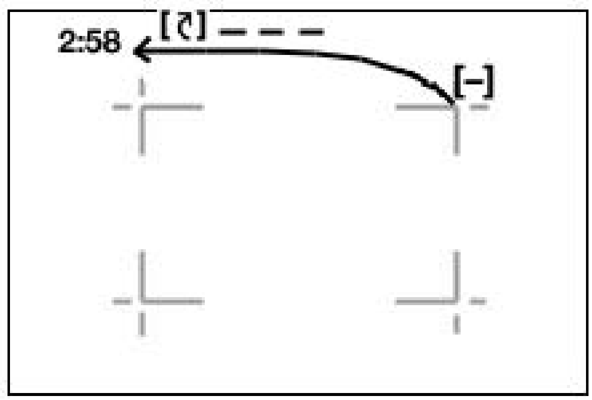
Lento



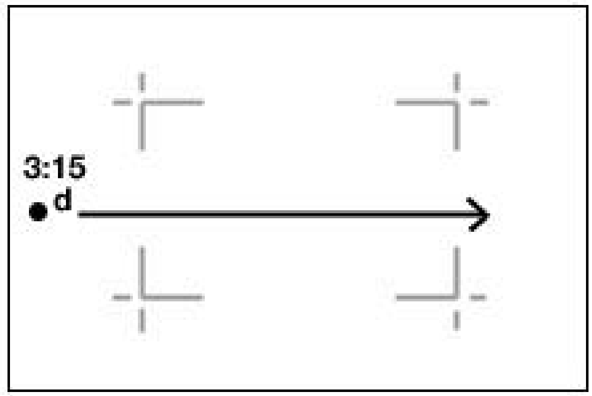
Allegro



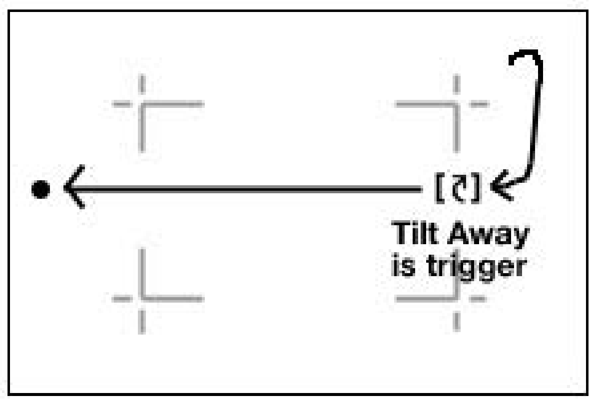
Vivace (match sound)
"Release Slingshot"



SECTION 4

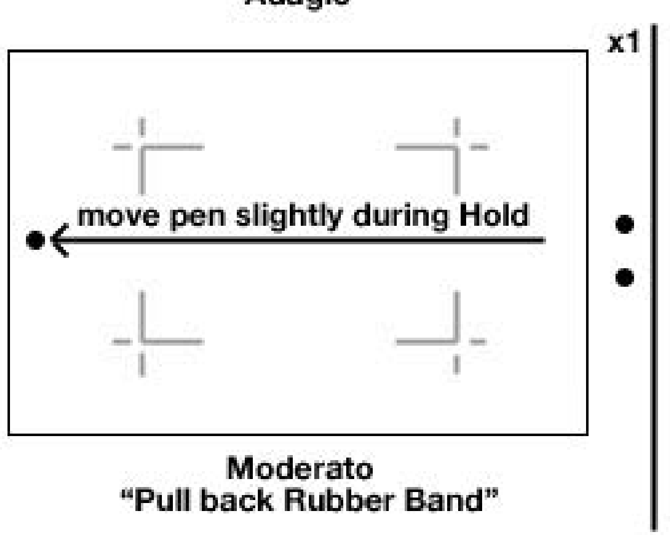


Adagio

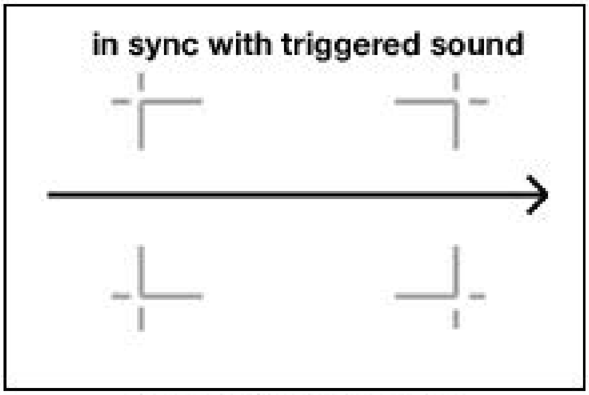


Adagio

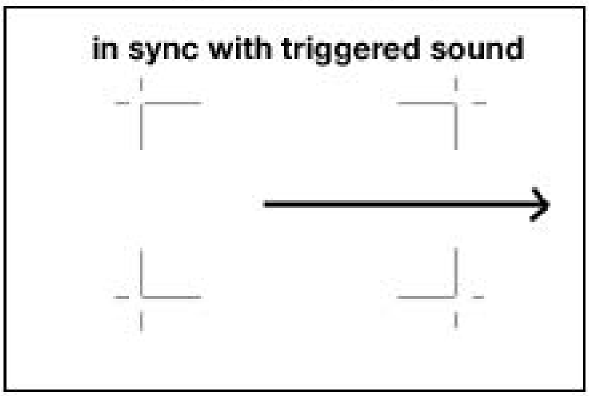
x1



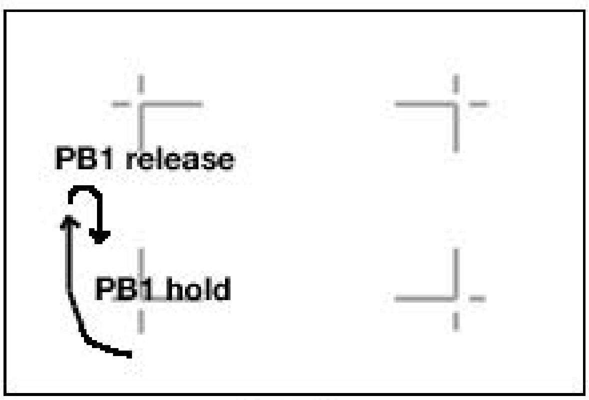
Moderato
"Pull back Rubber Band"



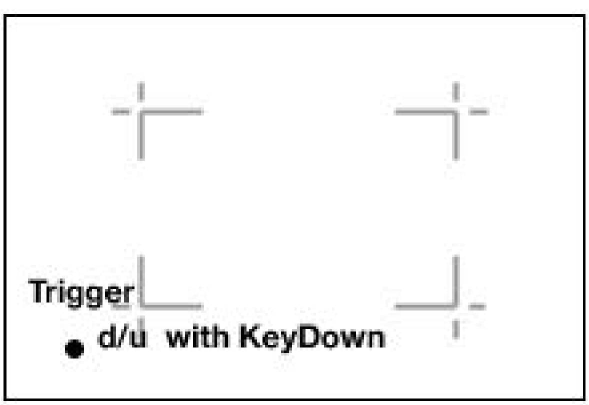
Vivace (match sound)
“Release Slingshot”

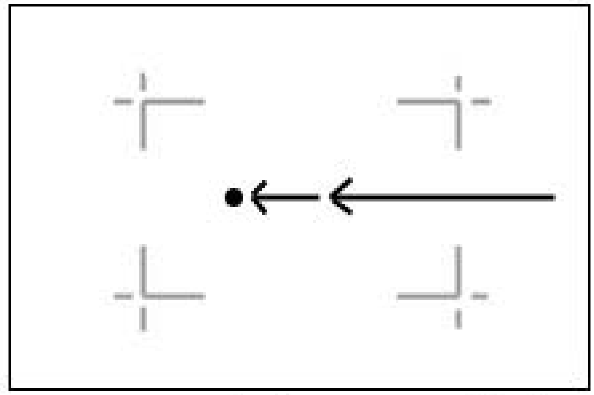


Vivace

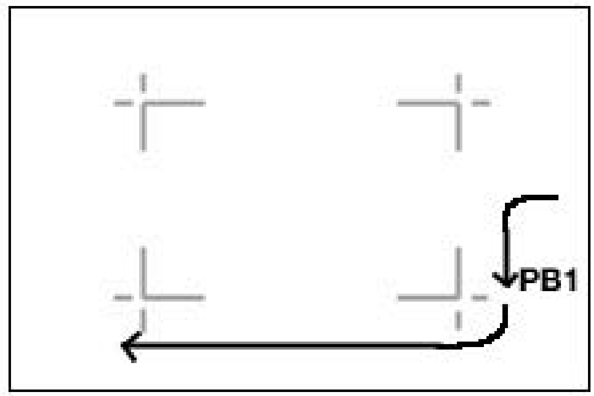


Adagio

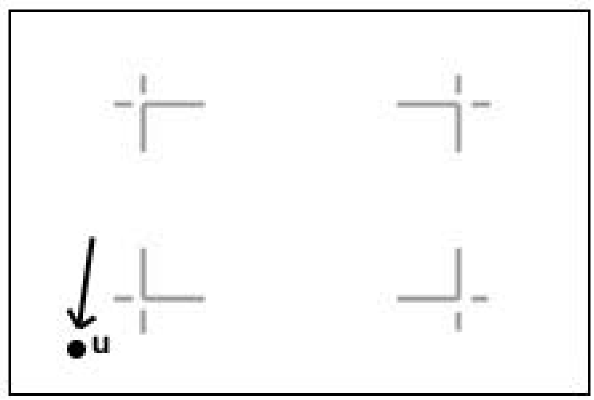


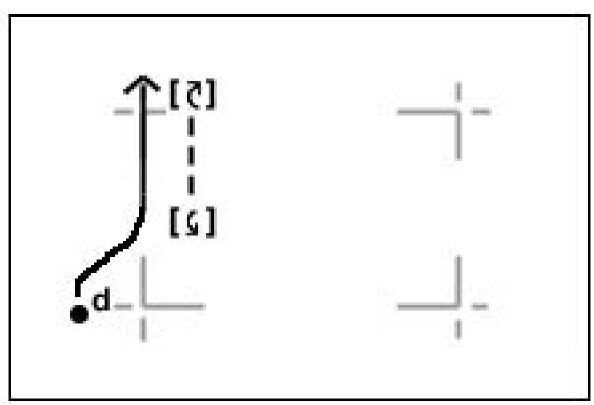


Lento << Adagio

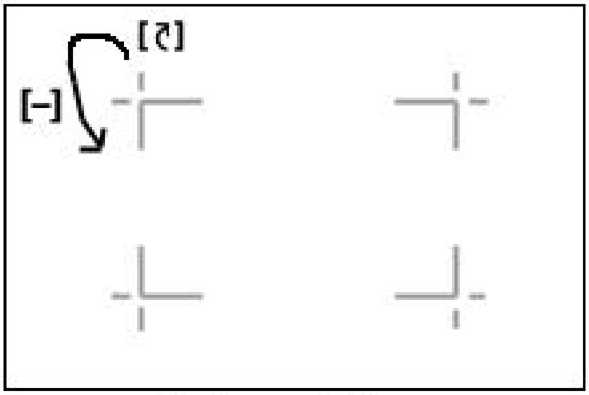


Allegro << Adagio

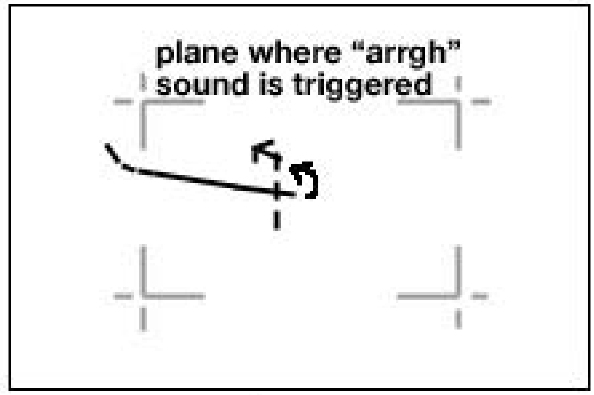




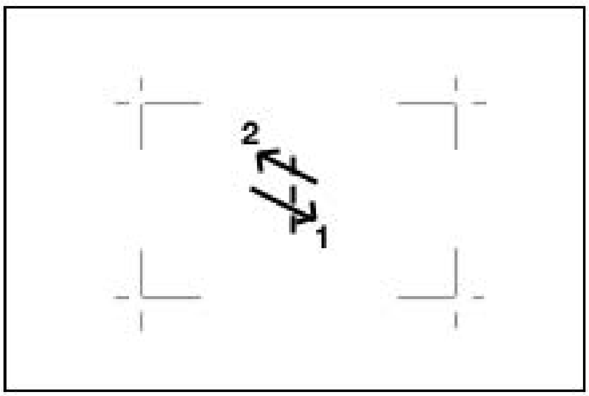
Largo

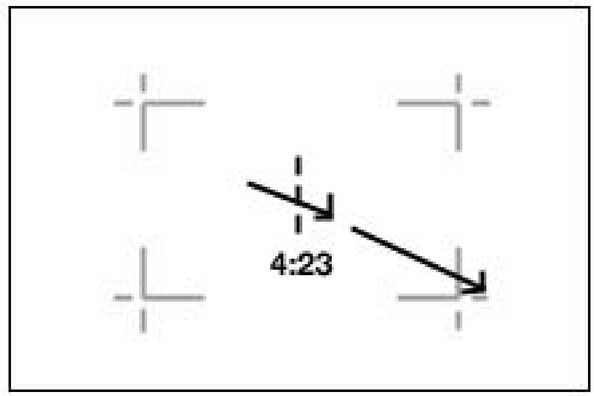


Moderato - Allegro

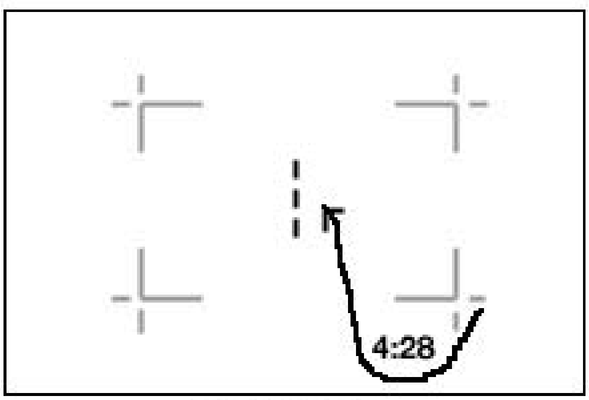


Largo

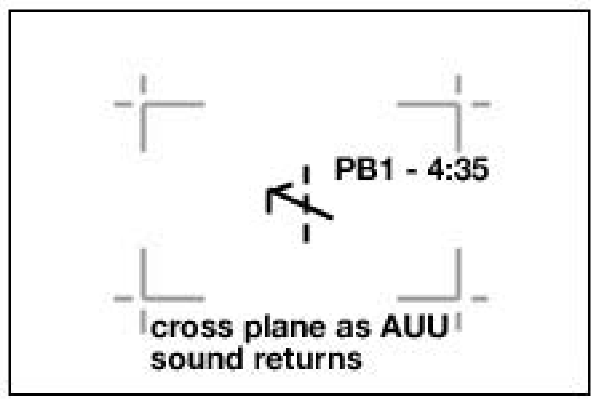


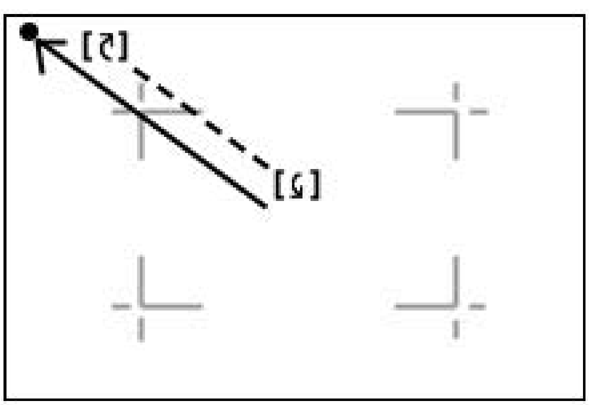


Moderato



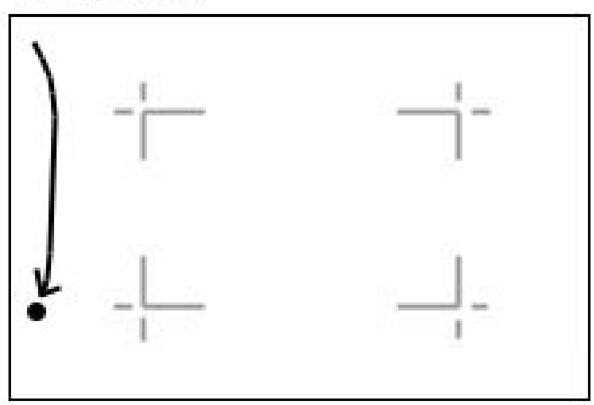
Molto Largo



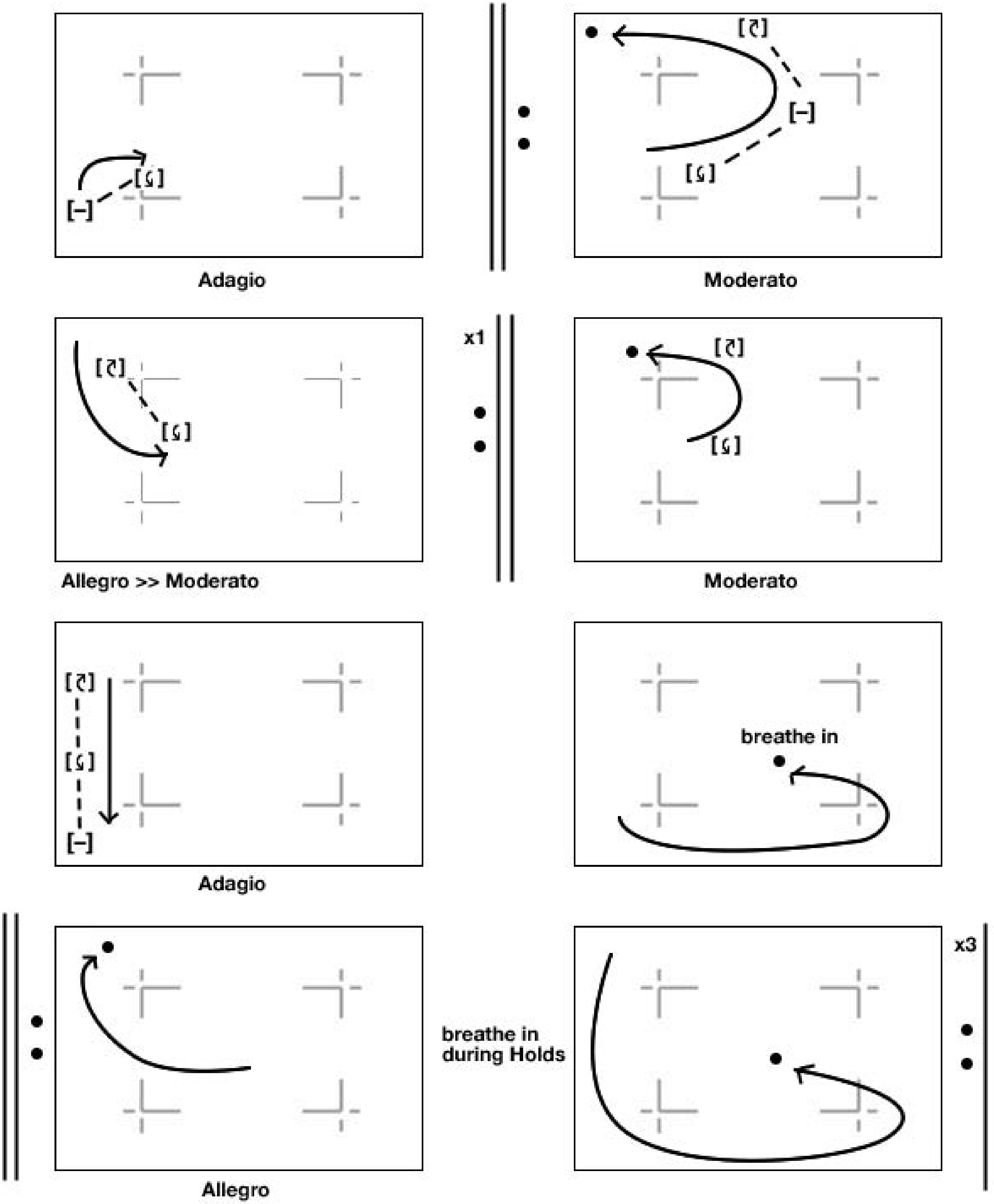


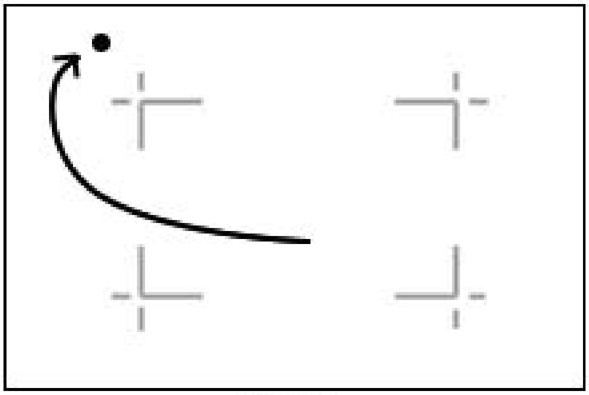
Largo

SECTION 5

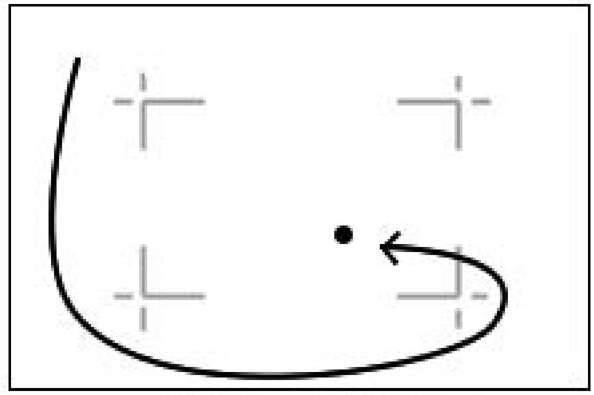


Adagio


Adagio
Moderato
x1
Allegro >> Moderato
Moderato
breathe in
Adagio
Allegro
breathe in during Holds
x3

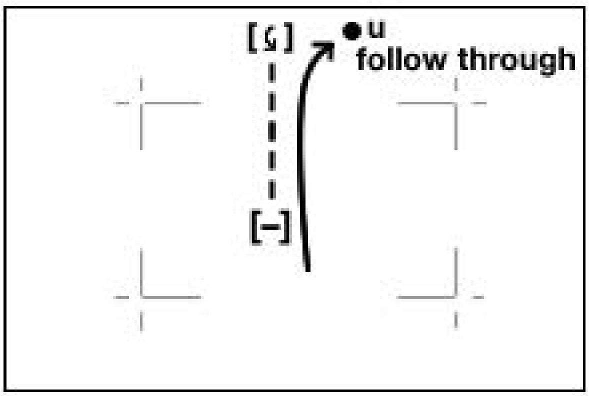


Allegro

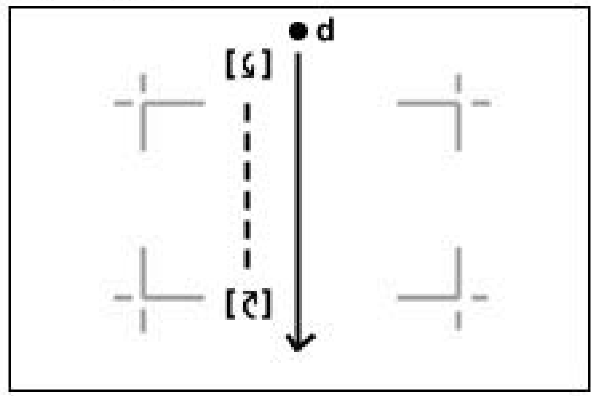


Allegro >> Moderato

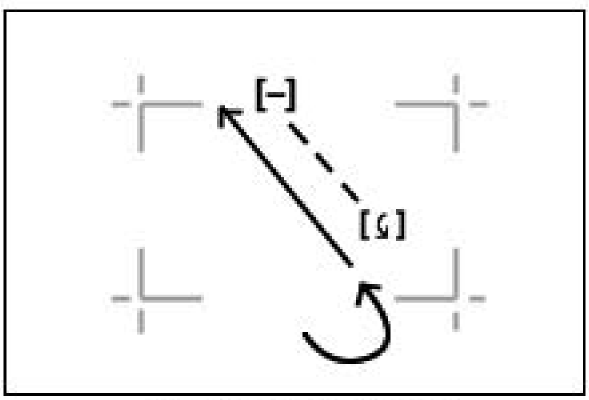
SECTION 6



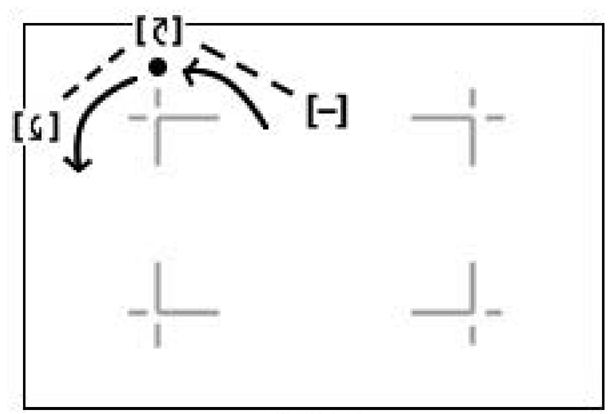
Largo



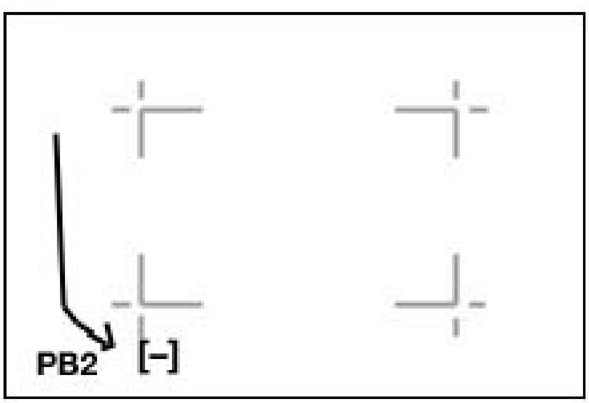
Adagio

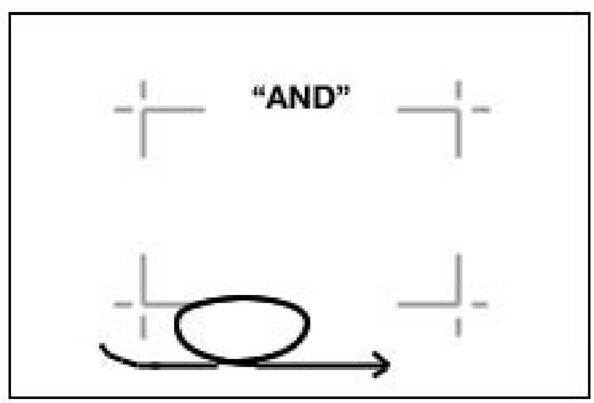


Moderato >> Allegro

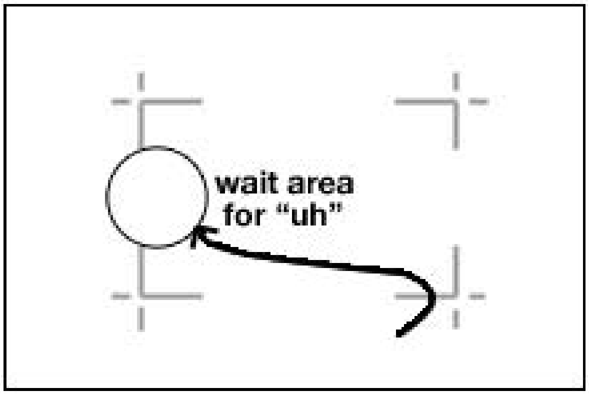


Adagio

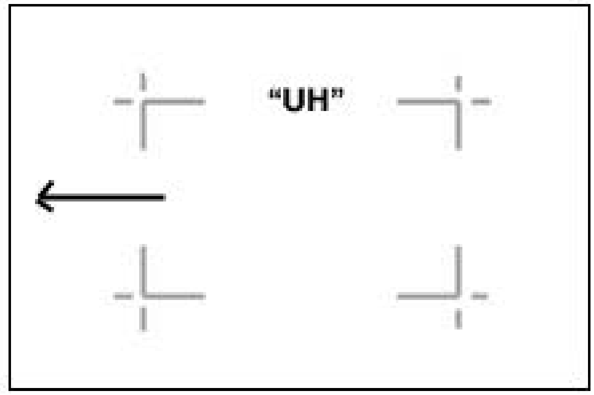




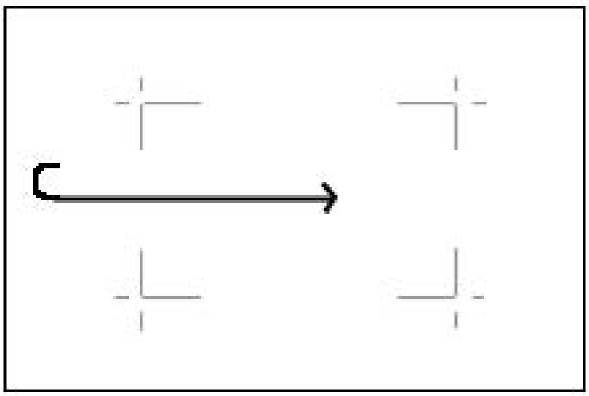
X-axis controls playback rate of “and”



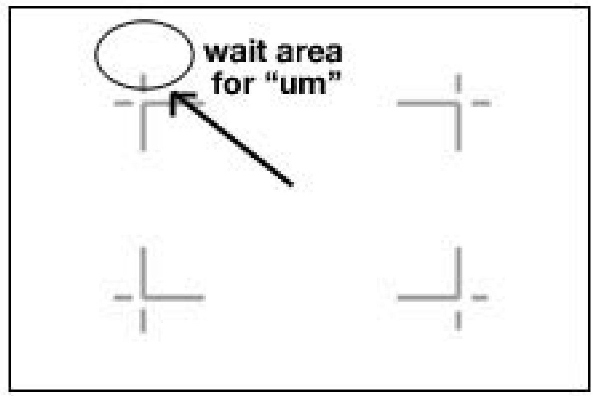
Allegro



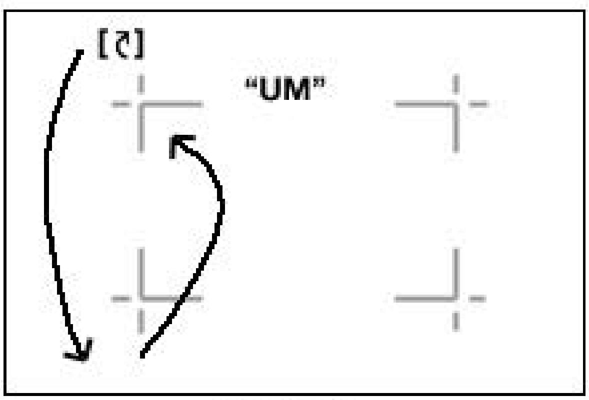
Lento



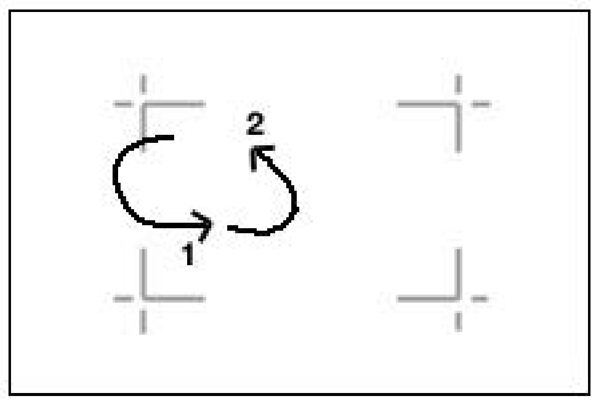
Moderato

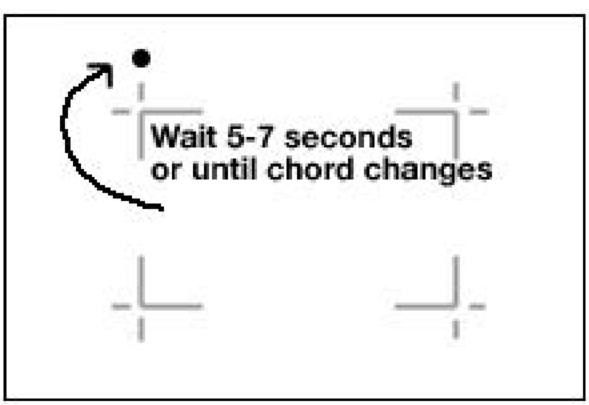


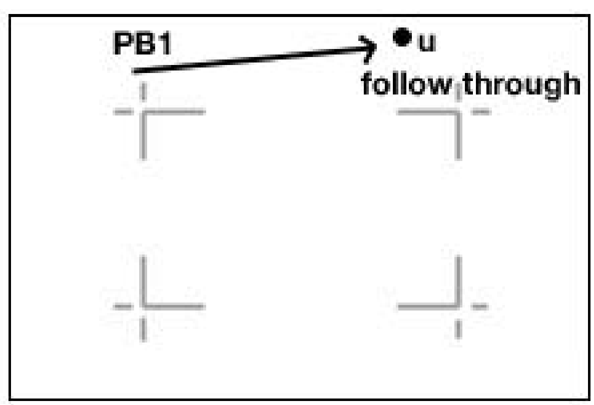
Allegro



Moderato







END

Lento

Smooch

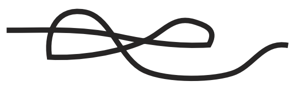
Wacom tablet
and Kyma

by Jon Bellona

dedicated to Gabriel Montufar

Notation remarks

- - - - - - - - - - - - - do not cross this line with pen


relative path of the pen (exploratory)

● up lift pen up off Wacom

● down place pen down on Wacom in a specific location


move back and forth along a path


PenTiltY, tilt in the direction of the magnet ends


target area


trace line on Wacom by lifting pen up off the tablet,
and placing back down onto the tablet. (pen up/down)
rapidly (staccato) or smoothly (legato)

□ panel 1 (page 1), indicates a piece of clear tape to aid
the performer in knowing where to start. Left edge of tape
indicates where breath/noise sound begins (X-axis).

Controller remarks

PenX: mapped to time domain of the sample file.

PenY: mapped to the frequency domain of the sample file.

PenTiltY: mapped to additional amplitude control.

Performance remarks

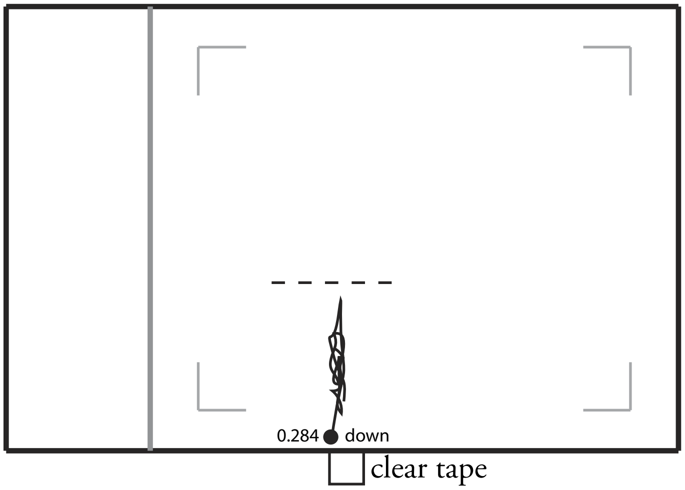
• Never stop moving the pen. Make micro-movements if lingering in a single spot. Micro-movements of the pen will add interest to the sound, otherwise emphasis will be given to sinusoidal oscillators, which decreases musical interest.

• Listen. While there is a choreographic score that accompanies this work, the performance requires one to listen how sound phrases develop that will, in turn, determine the lengths and dynamics of each subsequent phrase.

• Practice. The score should be memorized/internalized. The work requires the ear and hands to lead the piece, not the reading of a score. Make the piece your own!

• Remember to have fun. The sounds within may be comedic to some. The piece can be more, or less, serious depending on the performer.

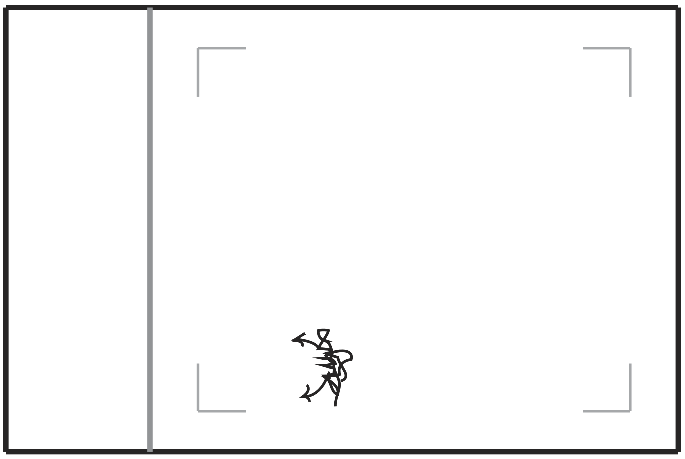
1



Slowly.
Explore a small vertical area that contains noise and breath material.
Play with noise as articulate phrases, making sure to breathe as well.

ca. 0:20

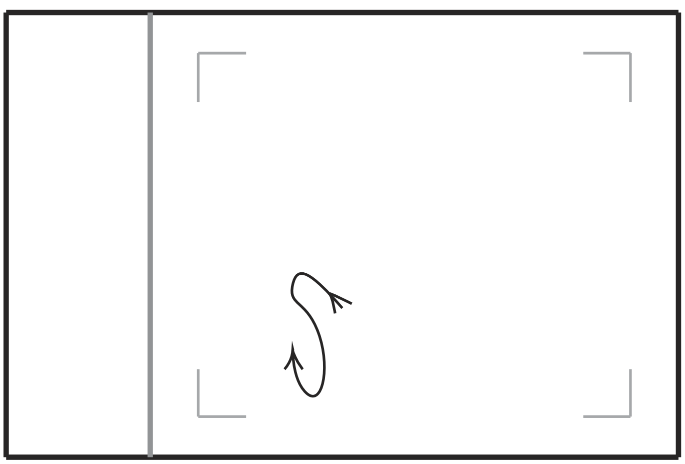
2



Maintain slow speed.
Arc to the left to produce pitched vocal formants.
Produce short (eighth to quarter note) tones before moving back into noise.
Introduce formants intermittently, precisely.

ca. 0:20

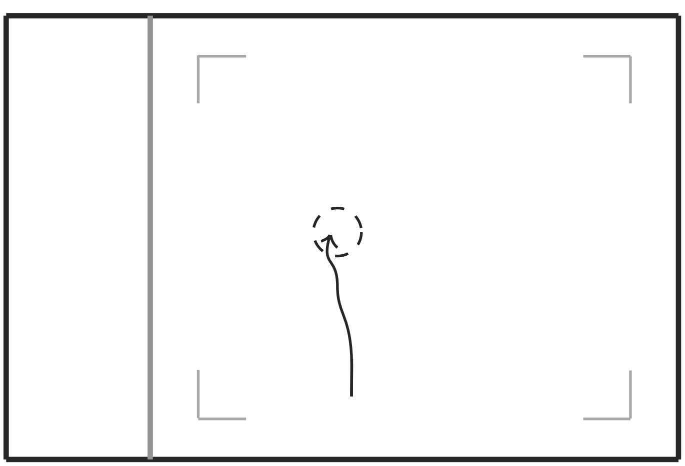
3



Larger gestures.
Articulate gestures with fast movements.
Improv/Free gestures. Spelling S M O O C H may help reach interesting formant & breath/noise material.

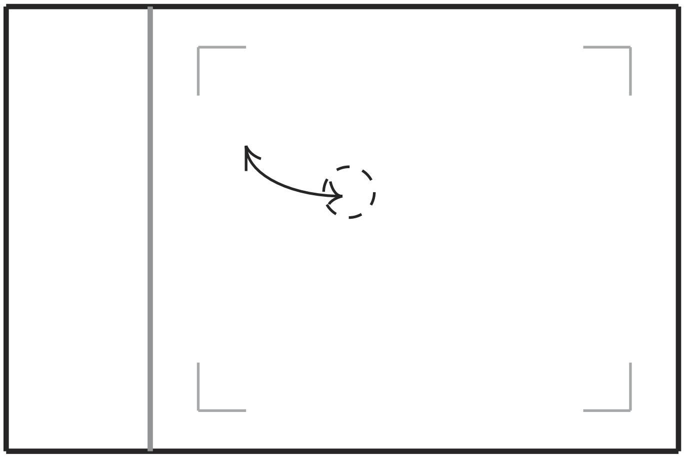
ca. 0:10 - 0:15

4



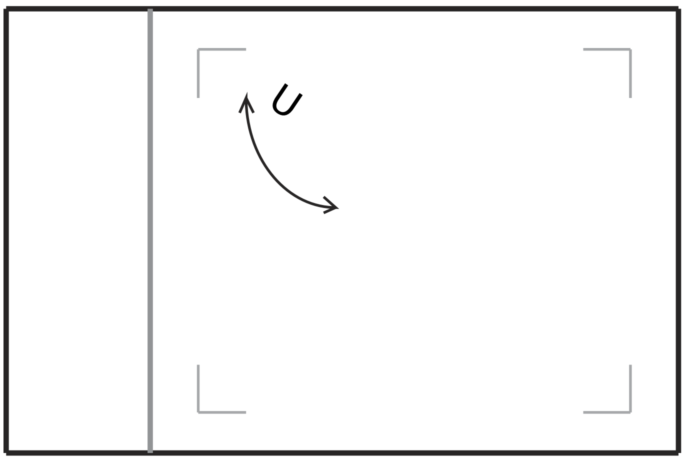
Quickly.
Move toward a ‘null’ or ‘breath’ area in the sound.
Move through noise/breath sounds to get there.

ca. 0:05

5


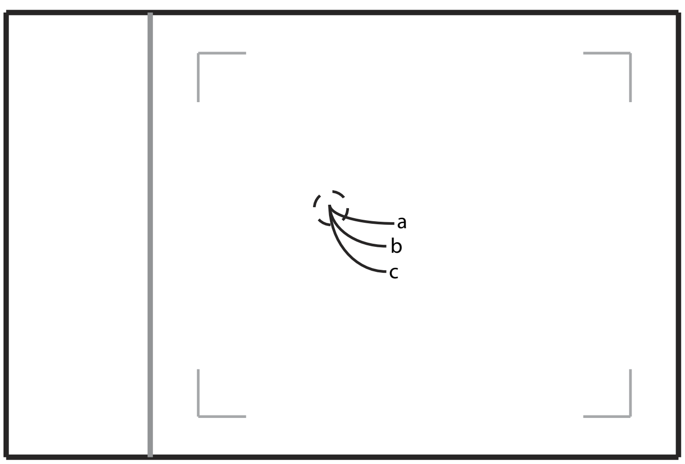
Quick gestures with time spent in target area.
Back and forth creates 'mmm' or 'mwah' sounds, like a kiss formed with lips.
Repeat a few times.

ca. 0:15

6


Faster gestures.
Increase vocal sounds (amplitude, density), by moving further up and into upper left quadrant, and by increasing PenTiltY.

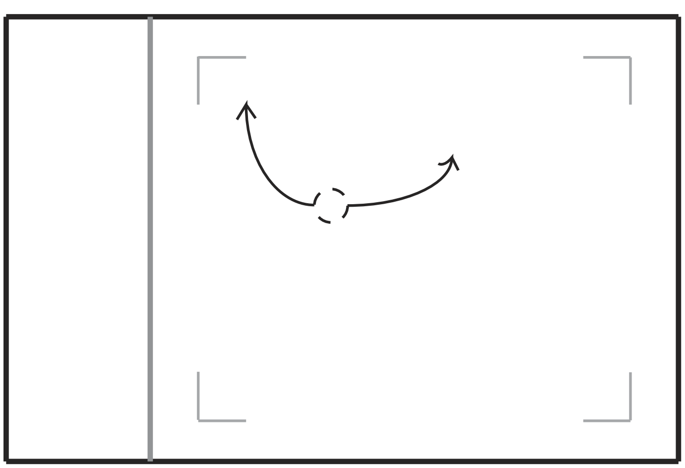
ca. 0:05 - 0:10

7


Start from target area
Go to 'a' and back.
Go to 'b' and back.
Go to 'c' and back.
(a, b, c) should all have unique frequencies.

LISTEN! for what these frequencies should be.

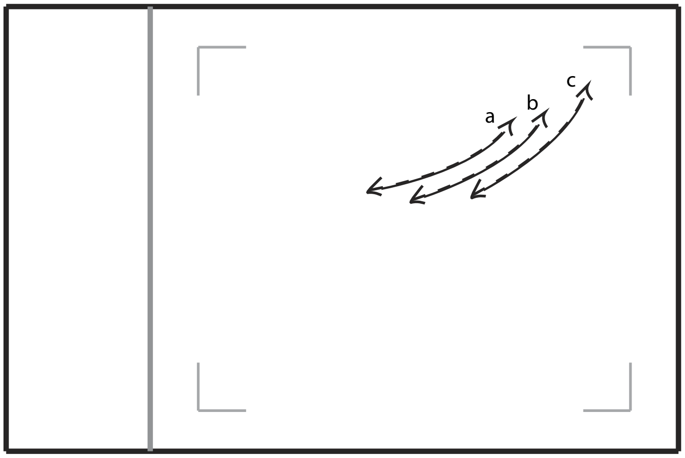
ca. 0:10

8


Faster, build up in intensity.
Add vocal sounds on right.
End phrase by pushing out to right of tablet.

ca. 0:05 - 0:10

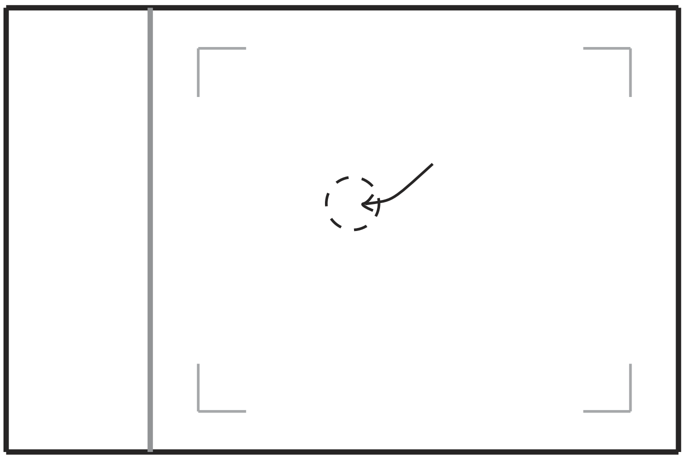
9



Rapidly.
As intensity and speed increase, quick staccato hits, tracing the line.
Follow this order of lines (a, b, c, b, a), slowing down and adding more pen down (legato) in final ‘b’, and ‘a’ lines. Think of the entire phrase as a single line that is transposed up and back down.

ca. 0:10

10

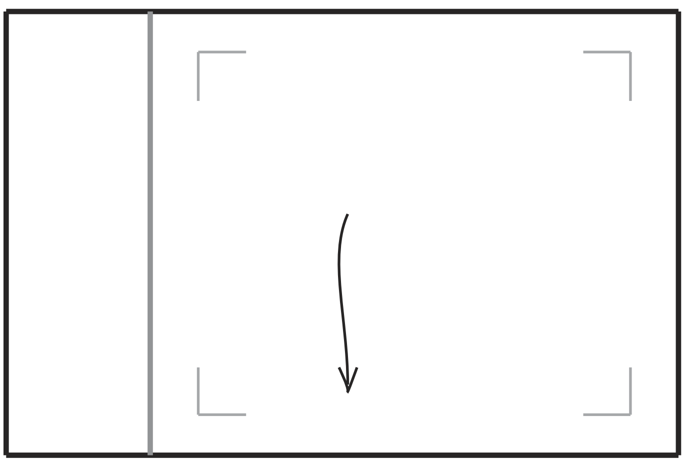


Complete phrase by quickly retreating back to target area (breath sound) and hang out here.

Alternate:
You may choose to go back to the panel 8 (page 2), or panel 2 (page 1) before continuing, if you wish.

ca. 0:05 unless alternate version, then longer.

11

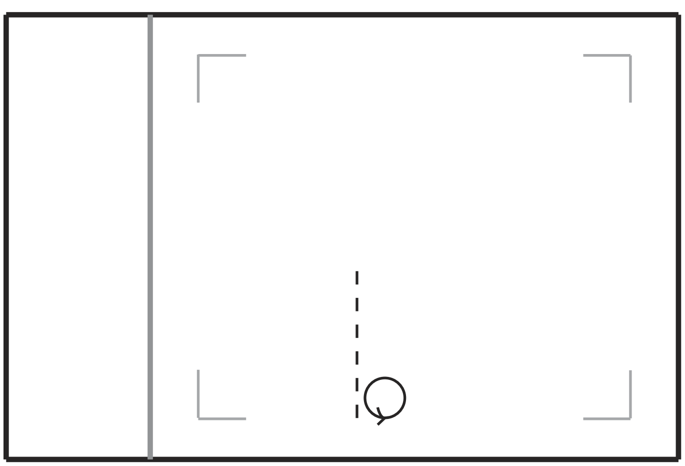


Really slow.
Decelerate as you go.
Fall along the breath/noise.

Alternate:
You may choose to pause and continue.
Pause and continue, as you trace the line.

ca. 0:15 - 0:20, unless alternate version.

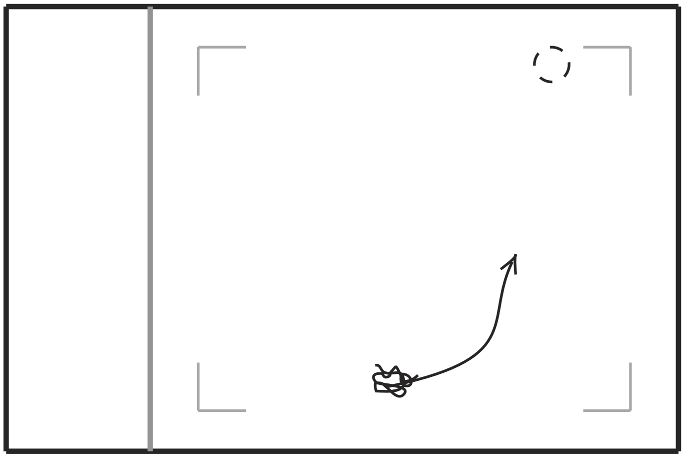
12



Regular handwriting pace.
Concentric circles with more vibrato
(tiny vibrations of pen)
Sound should be to the right of breath/noise, within low, vocal sound.

ca. 0:05

13

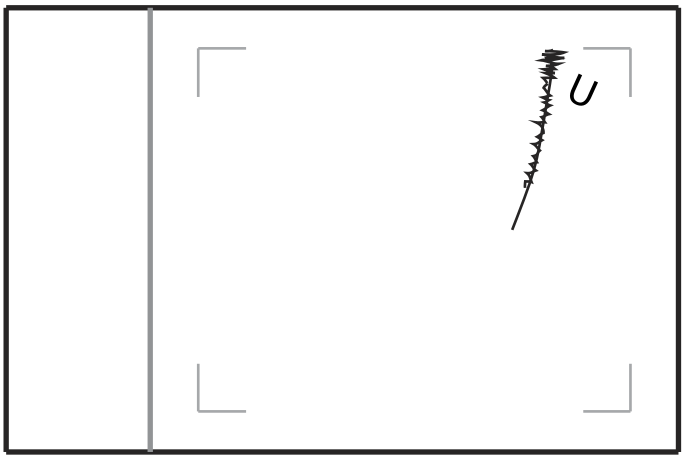


Decelerate out of circles, and then move extremely slowly.

Movement falls into straight line,
moving up toward upper right quadrant.

ca. 0:20 to move halfway up the tablet.

14

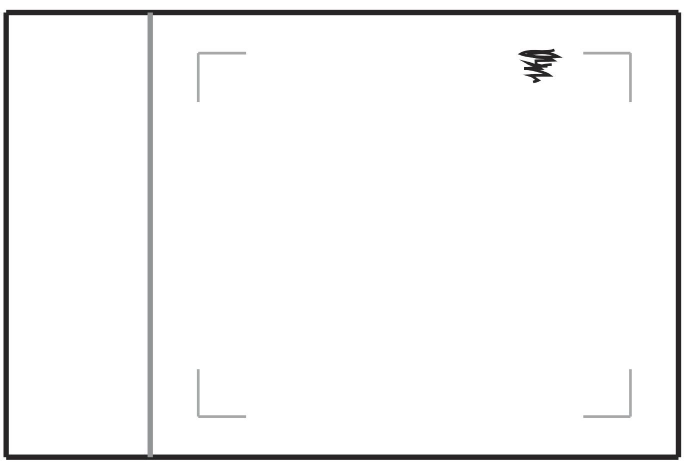


Continue to move slowly and steadily.
Build intensity by shaking the hand.
(This will add natural vibrato).

Increase PenTiltY.

ca. 0:15 to get near the top.

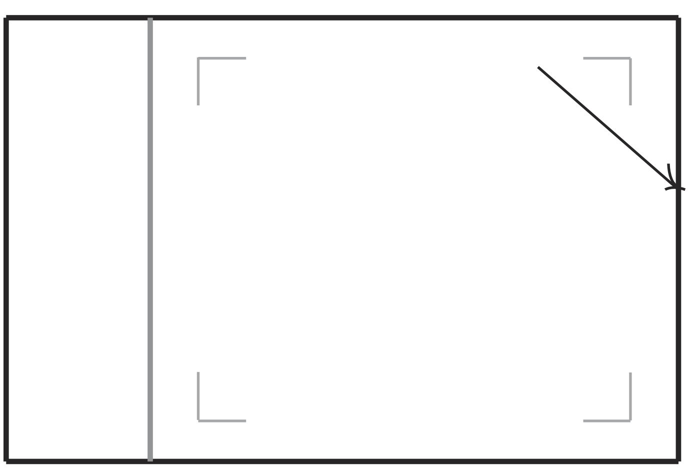
15



Hold and shake.
CLIMAX.
Hold as long as necessary.

Variable, from 0:08 - X duration

16



Rapidly.
Move the pen fast off the tablet.
Stay between 1/2 and 3/4 of the upper tablet.
(This will avoid a long reverb tail, which is unwanted).

ca. 1/2 second or less

END (ca. 3’00”)

Immaterial Vamp

for any number of players and instruments

PREPARATION

imagine a sound.
imagine how you will move to play that sound.

PERFORMANCE

Play your sound and repeat it.
Everyone listens together.
Everyone moves together (even if you are not moving).
You do not have to be in time with anyone else.

||: Repeat your sound for awhile (60-90 seconds).
Focus on both the sound and the movement required to make the sound.
Play with how your movement changes the sound, and how your sound changes your movement.
(After 60-90 seconds), slowly shift your sound into a different territory.
Your sound should shift by slowly changing your movement within the sonic phrase.
While shifting (in the moment), determine what sound-movement best fits with the ensemble.
Then repeat your movement-sound.
Play this sound and repeat it. **:|| (Repeat 3-6 times)**

within one of the repeats, the ensemble should reach FFF once. (The ensemble should choose beforehand)
within one of the repeats, the ensemble should reach ppp once. (The ensemble should choose beforehand)

the ensemble chooses how to start as an ensemble (rather than as individuals).

A. the ensemble opts to have everyone begin together (but moves away from each other throughout the piece)
B. individuals begin their sound without anyone else knowing when their sound will begin.

the ensemble chooses how to end as an ensemble (rather than as individuals).

A. the ensemble selects a single sound to merge towards and end the piece.
B. the ensemble selects a primary performer to cue an abrupt end.
C. the ensemble fades out one by one.

/////// **TCF4 (Study 1)** ///////

Controls:

Gametrak Z is amp
WiiA + WiiPitch - controls freq.
WiiTrigger + WiiRoll - controls time
WiiButtonDown - controls freeze

Instructions:

- start with WiiA and pitch down so low freq.
- small hand movements and low amp. (closer hands), slow movements widening to get a sense of sound
- when you add WiiB, you should shake your right arm to get a shaky sonic texture. with B keep hands close and low amp + low freq.
- occasionally accent the sound by thrusting left arm out to get an amplitude peak.
- continue for awhile. (:45 to 1 minute)
- get louder by slowly moving arms out so overall amp is louder AND add WiiA with increasing pitch (WiiPitch) [note: this requires practice]
- when you have a high pitched cross filtering sound and you are really shaking right arm withWiiB on, you have built up the tension of the work. [practice and listening]
- when the tension is good and ready, press WiiButtonDown and freeze the sound -- simultaneously freeze your body (to match).
- release (unfreeze) and continue frenetic movement including WiiB shake.
- you cannot do freeze/unfreeze too much with large phrases in between, but you can transition into quick freeze/unfreeze, so that freeze becomes a punctuation in a phrase rather than a distinct musical phrase.
- after freeze/unfreeze as punctuated phrases, find a moment to freeze and hold. This is discretionary -- hold a good sound.
- hold your body position and the sound for awhile. keep freezing WiiDown pressed.
- then ONLY move your left arm around and back to the initial holding place, so you alter the pitch and filter of the sound. and hold.
- make this left arm movement circle a phrase. repeat it a few times. slowly.
    - arm movements effect low-pass cutoff (Y) and chord notes (Z).

- change the sound by pressing and holding WiiA. (still keep freezing WiiDown pressed)

[note: you don't have to, but you can add theatric movement of pushing hands outward when triggering A]

- WiiA cuts out the low-pass filter, but keeps addition of chords possible (Z).

- hitting WiiB/Trigger cycles through new chord and depending on WiiRoll (L LC C RC R) picks a new root.

[note: mentally prepare for production of moving left arm and triggering new chords (rhythmically in tandem)]

-WiiButtonDown + WiiA press also enables directional triggers of Z

- when you think the audience has forgotten about the initial freneticism, or at least you have lulled them to forget, quickly release the freeze button, hold WiiB, shake right arm frantically, and spread arms out wide. we are in the finale.

- get really loud by shaking as much as possible and getting as wide as possible. this is the final tension. hold this tension here. don't know how long is effective, but effective is longer than you think.

- when you are ready, hold an extra second or two.

- now that you've held and are physically tired in brain and body, end the work by rapidly closing the arms together so the sound quickly slides into itself and cuts out.

-- if you extend this version it would be to freeze the freeze on indefinite loop, so you could add and play other sh** on top of it.

TauCrossfilter 4.mgd

Just one sound and reverb.

SG6VS (2017)
Form / Keyframes

arm motion = expand and contract along the coronal plane
track changes happen through Wii buttons

additive Track changes
Track 2 --- 1. (x2 arm motions)
Track 2 --- 2. (x2 arm motions)
Track 3 --- 1. (x2 arm motions)
Track 1 --- 1. (x2 arm motions)
Track 1 --- 2. (free form) build (requires Wii buttons)
Track 1 --- 3. (free form) build. freeze effect
before freeze Track 3 --- 0.
with freeze Track 2 --- 0.
with unfreeze Track 2 --- 2. (freeze/unfreeze x2)
last unfreeze Track 1 --- 4.
Track 1 --- 4 requires Wii buttons
ending: thumb under line, full outstretch arms freezes sound.
HOLD. look outward. and continue holding. pull all arms together to close sound. end.

HMW-mult3 (2017)

section 1. play chords and get sound. not too fast. explore the instrument's controls (for audience)

section 2. quiet rhythm (init loop) and exploring changes between 1 and 2. only one sound on at a time.

section 3. louder rhythm and getting more dissonant. section 3 can have both sounds on at once. section 2 and 3 can be like tuning a radio (Wii B searching the stations) in order to find a good timbre and tonal relationship. section 3 more so in the tuning (i.e. tuning can become more of a musical idea than a technique)

part of the performance is trying to get harmonics and staying there (slightly shifting).

ending. all off suddenly.

Appendix D

Alternate Controller Digital Musical Instruments

This list reviews alternate controllers, a subset of digital musical instruments. The list is non-exhaustive, and includes those instruments that contain a musical example of the alternate controller DMI or reference a document that discusses its music. Musical examples contain embedded href links unless specified.

Table D.1: Alternate Controller Digital Musical Instruments

Composer/Designer	**Alternate Controller DMI**	**Year**	**Classifier**	**Musical Example or Reference**
Nathan Asman	Curve	2017	Off-Body	Étude no. 1 (2017)
Jon Bellona	Distance-X	2016-17	On-Body	Trump Is a Fascist (2017)
Nathan Asman	LogDrum+	2016	Off-Body	LogDrum+ (2016)
Chi Wang	Myo, Kyma	2015	On-Body	Myotology (2015)
Federico Visi	Myo, computer	2015	On-Body	Tuned Constraint (2016)
Frederic Robinson, Cedric Spindler, Volker Böhm, Erik Oña	GePS	2015	On-Body	GePS Demo
Claude Woodward	Claudeatron Mk 1V	2015	Off-Body	Demo Video (YouTube)
Rodrigo Cadiz	Kara	2014	On-Body	Kara II (2014)
João Beira, Yago De Quay	Emotiv headset, computer	2014	On-Body	BioMediation (2015)
Dominik Hildebrand Marques Lopes	The Finger	2014	On-Body	08.06.2013 improv with Trio Brachiale
Jonathan Sparks	Nomis	2014	Off-Body	Website, NOMIS (2014)
Alberto Boem	SculpTon	2014	Off-Body	Demo Video (Vimeo)
Andrew McPherson, Victor Zappi	D-Box	2014	Off-Body	Demo Video (YouTube)
Martin Marier	Sponge	2014	Off-Body	Origami (2014)
Miriam Bleau	Soft Revolvers	2014	Off-Body	Soft Revolvers (2014)
Daniel Iglesia	Holophone	2014	Off-Body	Demo Video (Vimeo)
Alyssa Aska, Martin Ritter	MRLeap (LeapMotion, Max)	2014	Off-Body	Hyperkinesis (2014), described in ICMC 2014 proceedings
Lamtharn Hantrakul, Konrad Kaczmarek	LeapMotion, Max	2014	Off-Body	InCircles (2014), described in ICMC 2014 proceedings

Composer/Designer	Alternate Controller DMI	Year	Classifier	Musical Example or Reference
Chi Wang	LeapMotion, Kyma	2014	Off-Body	Soul Hermit (2014)
nu desine	Alphasphere	2014	Off-Body	Demo Video (YouTube)
Krysztof Cybulski	Elektrisk Oransje	2014	Off-Body	Demo Video (Vimeo)
John Mantegna	Emotiv headset, Kyma	2013	On-Body	Wetware Fantasy #1 (2013)
Christophe d'Alessandro	Cantor Digitalis	2013	Off-Body	Margaret Guthman Musical Instrument Competition, 2015
Chet Udell	eMotion (Max/MSP)	2013	On-Body & Off-Body	Project Videos on Website
Peter Bussigel	N-Dial	2012	Off-Body	Website
Nathan Bowen	iPhones, TouchOSC, Max/MSP	2012	Off-Body	4Quarters (2012), ICMC 2014 proceedings
Jon Bellona	Microsoft Kinect, simpleKinect, Kyma	2012	Off-Body	Casting (2013)
Imogen Heap et al.	MiMu Gloves	2011	On-Body	MiMu Gloves Demo (2012)
Onyx Ashanti	Beatjazz Exo-Voice Prosthesis	2011	On-Body	DEEPBLAK label party (2013)
Nathan Asman	Monome/Ableton	2011	Off-Body	T(Re)es (2017)
Frederic Bevilacqua, Interlude Consortium	MO	2011	Off-Body	Demo Video (Vimeo)
Michelle Nagai	MARtLET	2011	Off-Body	Demo Video (Vimeo)
Dualo	Du-Touch	2011	On-Body	Demo Video (YouTube)
Jon Bellona	Runner	2011	On-Body	Running Expressions (2011)
Alex Nowitz, Frank Baldé, Florian Goettke	Strophonion	2010-11	On-Body	STEIM process blog
Marco Donnarumma	Xth Sense	2010	On-Body	Ominous (2012-3)
Aurie Hsu	RAKS	2010	On-Body	shadows (2009-10), (Hsu 2012)
Claudio Bertin, Gabriel de Ioannes	Arcontinuo	2010	Off-Body	Demo Video (Vimeo), ICMC 2010 proceedings
Chikashi Miyama	Peacock	2010	Off-Body	Black Vox (2010)
Chikashi Miyama	Seven Eyes	2010	Off-Body	Demo Lecture Video (YouTube)
Gabriel Vigliensoni	SoundCatcher	2010	Off-Body	Demo Video (Vimeo)
Colin Raffel, Nick Kruge, Diane Douglas, Edgar Berdahl, Wendy Ju	Lattice Harp	2010	Off-Body	Music composition described in ICMC 2010 proceedings
Elena Jessop	VAMP	2009	On-Body	in Tod Machover's *Death and the Powers*, (NIME 2009)
Dan Overholt	The Fingers	2009	On-Body	NIME 2009 video url in paper broken
Steven Litt	CrudBox	2009	Off-Body	ITP Demo (2009)
Joseph Butch Rovan	GLOBE	2009	On-Body & Off-Body	of the survival of images (2013)
Koray Tahiroglu, Hannah Drayson, Cumhur Erkut	IBIS	2008	On-Body	ICMC-2008 conference demo
Jordan Bartee	Bent Gear	2008	On-Body	Bent Gear (2009), DVD on (Nicolas Collins 2009)
Kevin Patton	Digital Poplar Consort	2008	Off-Body	MEME Ensemble, 2008
David Litke	Spectral Glove (P5 Glove)	2007	On-Body	from that which could (2007)
Kevin Patton	AmbiDextron	2007	On-Body	Creaking the Air (2008)
Nicolas d'Alessandro	HandSketch	2007	Off-Body	Improvisation for Disturbed Voice
Chester Udell	After Math	2007	Off-Body	(ibid., p. 279), Website
Juhani Räisänen	Sormina	2007	Off-Body	Demo Video (YouTube)
Luke Dahl, Nathan Whetsell, John Van Stoeker	WaveSaw	2007	Off-Body	Website
Mark Zadel	Different Strokes	2006	Off-Body	Demo, 2012
Joseph Malloch, Andrew Stewart	T-Stick	2006	Off-Body	T-Stick (2009) with Fernando Rocha
Jaime Oliver, Matthew Jenkins	Silent Drum	2006	Off-Body	Demo Video (YouTube) Jaime Oliver website
Chikashi Miyama	Qgo	2006	Off-Body	NIME 2008 performance
Zach Layton	EEG/Bluetooth/Max	2005	On-Body	Megawatt Mind (2010)
Pierre-Yves Fortier, Mark Marshall	FM Gloves	2005	On-Body	FM Gloves (2010)
Tomomi Adachi	Right Hand	2005	On-Body	Voice and the Right Hand (2005-6)
Martin Kaltenbrunner, Sergi Jordá, Gunter Geiger, Marcos Alonso	Reactable	2005	Off-Body	Transmediale performance, 2007
Mark T. Marshall	T-Box	2005	Off-Body	Demo Video (YouTube), IDMIL project page
Leon Gruenbaum	Samchillian Tip Tip Tip Cheeepeeee	2005	Off-Body	Demo Video (YouTube)
Sidney Fels, Florian Vogt, Graeme McCaig, Sachiyo Takahashi, Linda Kaastra	Tooka	2004	Off-Body	University of British Columbia Research Page
Tomomi Adachi	Voice, Infrared Sensor Shirt	2004	Off-Body	Voice and Infrared Sensor Shirt
Yoichi Nagashima	MiniBioMuse III	2003	On-Body	BioCosmicStorm-II (2001)

Composer/Designer	Alternate Controller DMI	Year	Classifier	Musical Example or Reference
Mark Gunderson	Thimbletron	2003	On-Body	Thimbletron, Website
Loic Kessous, Daniel Arfib	Scan Glove	2003	On-Body	Described in NIME 2003 proceedings
Christopher Dobrian, Frederic Bevilacqua	Vicon-8, MCM, Max/MSP	2003	Off-Body	NIME 2003 demo
Motohide Hatanaka	Bento-Box	2003	Off-Body	Description in NIME 2003 proceedings
Michael Lyons, Michael Haehnel, Nobuji Tetsutani	Mouthsizer	2003	Off-Body	Description and figure in (Miranda and Wanderley 2006, p. 65-6), (Lyons et al. 2003)
Jon Satrom	The Vitch	2002	Off-Body	The Vitch
Robert Huott	Ski	2002	Off-Body	NIME 2002 proceedings, url to sounds no longer working
Leila Hasan, Nicholas Yu	Terememova	2002	Off-Body	Demo Video at NIME 2002
Nicolas Collins	Sled Dog	2001	Off-Body	(Nicolas Collins 2009, p. 111), Live Performance, 2002
Jerry Riopelle	Beamz	2001	Off-Body	Consumer Website
Roberto Aimi, Diana Young	Beatbugs	2001	Off-Body	Nerve, by Gil Weinberg, described in ICMC 2004 proceedings
Michel Waisvisz	The Hands v3	2000	On-Body	No Backup concert (2004)
Max Mathews	Radio Baton	2000	Off-Body	Max Mathews Demo (YouTube)
Atau Tanaka, Bert Bongers, Kasper Toeplitz	Global String	2000	Off-Body	Video Document (Vimeo)
Ms. Pinky	Interdimensional Wrecked System	2000	Off-Body	StarBalls, by Mr. Sakitumi (YouTube), Website
Bert Bongers, Yolande Harris	Video-Organ	2000	Off-Body	Inside-Out (2002)
Zbigniew Karkowski	IR Cage	1990s	Off-Body	DEAF94 concert
Joe Paradiso	Dancing Shoes	1999	On-Body	Expressive Footwear
Tina Blaine, Tim Perkins, Clifton Forlines	Jam-O-Drum	1998-2006	Off-Body	Bounce Game Demo (YouTube), Website
Teresa Marrin	Conductors Jacket	1998	On-Body	Music on CD in (Battier and Wanderley 2000)
Sergi Jordá	ExoSkeleton	1998	On-Body	Afasia (1998), (NIME 2002)
Mark Bromwich, Julie Wilson	Bodycoder System	1998	On-Body & Off-Body	The Suicided Voice (2016)
Suguru Goto, Patrice Pierrot	Body Suit	1997	On-Body	netBody (2008)
Alain Baumann, Rosa Sanchez	IO.zn Glove	1997	On-Body	Interface Osmòtic (1997) (NIME 2002)
Butch Rovan	Glove Controller	1997	On-Body	Continuities (1997)
Leonello Tarabella	Twin Towers	1997	Off-Body	MarsLight (1997), video excerpt in (ibid.), Twin Talk (2002)
X-Music; Roland	Dimension Beam	1997	Off-Body	Described in Sound on Sound (June 1997)
Joe Paradiso, Neil Gershenfeld	Sensor Chair	1997	Off-Body	MIT Media Lab Website with demos
Wayne Siegel, Jens Jacobsen	Digital Dance System (DIEM)	1996	On-Body & Off-Body	Movement Study (1996), (Siegel and Jacobsen 1998)
Roel Vertegaal	SensOrg	1996	Off-Body	Description in SMC 1998 paper
Sensorband, Bert Bongers, Theo Borsboom	Soundnet	1996	On-Body & Off-Body	SoundNET (1996)
Russell Pinkston	MIDI Dance Floor	1995	Off-Body	Memory of Absence (1994), Centaur Records 2764, 2005
Ed Severinghaus, Chris Van Raalte, Pamela Z	BodySynth™	1994	On-Body	BodySynth demo (2002)
Walter Fabeck	Chromasone	1994	On-Body & Off-Body	Fuze (1994)
Yamaha	Miburi	1994	On-Body	Ex'Realm showcase 2009
Marie Goyette	MIDI belt, MIDI shoes	1993	On-Body	'Mananangaal/Women Soignees' with Laetitia Sonami (1993)
Michel Waisvisz	The Web	1993	Off-Body	Gaudeamus Electronic Music Festival, 2006, de Zoetgevooisde Bliksem Festival program, 1993
Atau Tanaka, Benjamin Knapp, Hugh Lusted	BioMuse	1992	On-Body	Tibet (2001)
Brad Cariou	aXiø(alternative eXpressive Input Object)	1992	Off-Body	Prelude (1993)
Ray Edgar	Sweatstick	1992	Off-Body	Flexonica II (1992-3), Vasulka Archive
Joanne Cannon	Contra Monster	1992	Off-Body	Bent Leather Band 2010 performance
Will Bauer, Bruce Foss	GAMS	1992	Off-Body	Music described in (Bauer and Foss 1992)
Stuart Favilla	Light Harp	1992	Off-Body	Bent Leather Band 2010 performance
Laetitia Sonami, Bert Bongers	Lady's Glove	1991	On-Body	Mechanization Takes Command (1991)
Eric Johnstone	Podoboard	1991	Off-Body	Alain LaMontagne, (ICMC 1991)
Don Buchla	Buchla Lightning	1991	Off-Body	7 Styles in 7 minutes (1999)

Composer/Designer	Alternate Controller DMI	Year	Classifier	Musical Example or Reference
Tod Machover	Dexterous Hand Master	1980s	On-Body	Bug-Mudra
Bernard Szajner	Laser Harp	1980s	Off-Body	Syringe (1980)
Steve Hogarth	MIDI Glove	1989	On-Body	No One Can (Marillion)
Paul DeMarinis	Power Glove	1989	On-Body	The Power of Suggestion (1991)
Serge de Laubier	Meta-Instrument	1989	On-Body	Visual Duo (2012)
EMS	Soundbeam	1989	Off-Body	Sound on Sound Review
Michel Waisvisz, Bert Bongers	The Hands v2	1988	On-Body	De Zoetgevooisde Bliksem Festival (1993)
Edwin van der Heide, Bert Bongers	MIDIConductor (The Hands)	1988	On-Body	Sensorband (Bongers 2007; Tanaka 2000)
Simon Veitch	3DIS (3D interactional space)	1988	Off-Body	Mentioned in NIME 2011 proceedings
Michael Starkier, Philippe Prevot	Pacom	1986	Off-Body	Music described in 1986 ICMC paper
Nicolas Collins	Devils Music	1985	Off-Body	Album download
Michel Waisvisz	The Hands	1984	On-Body	The Hands (Movement I) (Waisvisz 1987)
The HUB	MIDI Hub and computers	1984	Off-Body	The Hub, Artefact Recordings, 1989
Jacque Serrano	Interactif Spatio-Musical/Temporel	1984	Off-Body	Described in (Miranda and Wanderley 2006, p. 137), (Braun 2002, p. 46)
David Rokeby	Very Nervous System	1982	Off-Body	Documentation Video (Vimeo)
League of Automatic Composers	Kim-1 computers	1978	Off-Body	New World Records, 2007
Iannis Xenakis	UPIC	1977	Off-Body	Temps Reèl (1989) described in (Bernard 1991)

Appendix E

Audio and Video Example URLs

Table E.1: Audio Example URLs

Audio Example	**URL**
Audio 2-1	http://jpbellona.com/public/dissertation/audio/ex-OBOF-scrub-multisax-sampleHold-faderRate-asInterval-master.mp3
Audio 2-2	http://jpbellona.com/public/dissertation/audio/ex-OBOF-multigrid2-short-master.mp3
Audio 3-1	http://jpbellona.com/public/dissertation/audio/ex-JBrownIGotYou-dataZoom.mp3
Audio 3-2	http://jpbellona.com/public/dissertation/audio/ex-MaceoParker-ShakeEverythingYouGot-solo.mp3
Audio 3-3	http://jpbellona.com/public/dissertation/audio/ex-datarecall-obof-arrayStorageSampFreq-edit.mp3
Audio 3-4	http://jpbellona.com/public/dissertation/audio/ex-datarecall-greatspeeches.mp3
Audio 3-5	http://jpbellona.com/public/dissertation/audio/ex-datarecall-obof-delayIntoTimeIndex-edit.mp3
Audio 3-6	http://jpbellona.com/public/dissertation/audio/ex-datarecall-obof-delayIntoTimeindexMultiParams-edit.mp3
Audio 3-7	http://jpbellona.com/public/dissertation/audio/ex-noise-linear-noReson.mp3
Audio 3-8	http://jpbellona.com/public/dissertation/audio/ex-noise-nonlinear-noReson.mp3
Audio 3-9	http://jpbellona.com/public/dissertation/audio/ex-bellsbeating-pseudoRandom-excerpt-attack.mp3

Audio Example	URL
Audio 3-10	http://jpbellona.com/public/dissertation/audio/ex-bellsbeating-noRandom-excerpt.mp3
Audio 3-11	http://jpbellona.com/public/dissertation/audio/ex-particle-panSpread.mp3
Audio 3-12	http://jpbellona.com/public/dissertation/audio/ex-particle-freqSpread-twoOct.mp3
Audio 3-13	http://jpbellona.com/public/dissertation/audio/ex-wacom-paritcle-LPFspread-gtr.mp3
Audio 3-14	http://jpbellona.com/public/dissertation/audio/ex-gametrak-particle-acousticspace.mp3
Audio 3-15	http://jpbellona.com/public/dissertation/audio/ex-wacom-datazoom.mp3
Audio 3-16	http://jpbellona.com/public/dissertation/audio/ex-wacom-reverb.mp3
Audio 3-17	http://jpbellona.com/public/dissertation/audio/ex-wacom-sampleSelection-scorpio-edit2.mp3
Audio 3-18	http://jpbellona.com/public/dissertation/audio/ex-wacom-particle-speedTrigger.mp3
Audio 3-19	http://jpbellona.com/public/dissertation/audio/ex-wacom-particle-velocityFreq.mp3
Audio 3-20	http://jpbellona.com/public/dissertation/audio/ex-wacom-spectralFilter-Bandpass2.mp3
Audio 3-21	http://jpbellona.com/public/dissertation/audio/ex-wacom-spectralFilter-HPFilter.mp3
Audio 3-22	http://jpbellona.com/public/dissertation/audio/ex-gametrak-spatialization.mp3
Audio 3-23	http://jpbellona.com/public/dissertation/audio/ex-gametrak-scratch-mode.mp3
Audio 3-24	http://jpbellona.com/public/dissertation/audio/ex-gametrak-freeze.mp3
Audio 3-25	http://jpbellona.com/public/dissertation/audio/ex-gametrak-chordarray.mp3
Audio 3-26	http://jpbellona.com/public/dissertation/audio/ex-wii-couplingmiles.mp3
Audio 4-1	http://jpbellona.com/public/dissertation/audio/excerpt-NullSet-20170508.mp3
Audio 5-1	http://jpbellona.com/public/dissertation/audio/Immaterial-Vamp-master-20170325.mp3

Audio Example	URL
Audio 6-1	http://jpbellona.com/public/dissertation/audio/ex-gametrak-randSampByMemWriterx2-scratch.mp3
Audio 6-2	http://jpbellona.com/public/dissertation/audio/ex-sg6-noCopies-noFreq-gate.mp3
Audio 6-3	http://jpbellona.com/public/dissertation/audio/ex-sg6-noCopies-gate.mp3
Audio 6-4	http://jpbellona.com/public/dissertation/audio/ex-sg6-17copies-gate.mp3
Audio 6-5	http://jpbellona.com/public/dissertation/audio/excerpt-CDM-20150107.mp3
Audio 6-6	http://jpbellona.com/public/dissertation/audio/ex-tau-timeLocation-selections.mp3
Audio 6-7	http://jpbellona.com/public/dissertation/audio/ex-interim-bhills.mp3
Audio 6-8	http://jpbellona.com/public/dissertation/audio/ex-interim-carbonfeed.mp3
Audio 6-9	http://jpbellona.com/public/dissertation/audio/ex-interim-freedomFeel.mp3
Audio 7-1	https://open.spotify.com/track/0AX2BuHoHodrmrYc4mA3fi?si=M_Sni5x9QWGScqzOcxS9UA

Table E.2: Video Example URLs

Video Example	URL
Video 1-1	https://www.youtube.com/watch?v=aaYE1TQGIvk
Video 1-2	https://vimeo.com/86766860
Video 1-3	https://vimeo.com/111958754#t=30s
Video 1-4	https://www.youtube.com/watch?v=EK1Q7X_c3Q8
Video 1-5	https://www.youtube.com/watch?v=ncrS9jmh-Uw
Video 1-6	https://www.youtube.com/watch?v=LTytHbZG0p8
Video 1-7	https://www.youtube.com/watch?v=TwYzSiDgPIk
Video 3-1	https://vimeo.com/27388869
Video 3-2	https://vimeo.com/27388869
Video 4-1	https://www.youtube.com/watch?v=AUaK9-qiJ6M
Video 4-2	https://vimeo.com/119409969
Video 4-3	https://vimeo.com/119409970

Video Example	URL
Video 4-4	https://vimeo.com/139088847
Video 4-5	https://www.youtube.com/watch?v=7KkTzxg5hug
Video 4-6	https://www.youtube.com/watch?v=CZzsJ8iuI0w
Video 4-7	https://www.youtube.com/watch?v=kw44pLTIm4E
Video 5-1	https://youtu.be/KJ4cvInxGQA?t=3m40s
Video 6-1	https://youtu.be/gn1rqBoV9I0
Video 6-2	https://vimeo.com/141900051
Video 6-3	https://vimeo.com/217241538
Video 6-4	https://youtu.be/8fVc4B4WWZY
Video 6-5	https://youtu.be/sNvZYH_bth8
Video 6-6	https://youtu.be/hBBQ4QoYlmk
Video 6-7	https://youtu.be/xLdPeDfhbII
Video 6-8	https://youtu.be/ILTMSBsCjZc
Video 6-9	https://youtu.be/nzCMKPXxRJY
Video 6-10	https://vimeo.com/223972736
Video 6-11	https://youtu.be/Rwq_4U0EjkI
Video 6-12	https://youtu.be/kEhGMg6zrcs
Video 6-13	https://youtu.be/YchCNYLiIUM
Video 7-1	https://vimeo.com/48919422
Video 7-2	https://vimeo.com/7849421
Video 7-3	https://vimeo.com/19372180
Video 7-4	https://vimeo.com/109211210
Video 7-5	https://vimeo.com/205151696

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