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TOWARD AN EXPANDED ACTION-ORIENTED ONTOLOGY FOR DIGITAL MUSICAL PERFORMANCE

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Abstract

Musical performance using digital musical instruments has obfuscated the relationship between observable musical gestures and the resultant sound. This is due to the sound producing mechanisms of digital musical instruments being hidden within the digital music making system. The difficulty in observing embodied artistic expression is especially true for musical instruments that are comprised of digital components only. Despite this characteristic of digital music performance practice, this thesis argues that it is possible to bring digital musical performance further within our action-oriented ontology by understanding the digital musician through the lens of Lévi-Strauss' notion of the bricoleur. Furthermore, by examining musical gestures with these instruments through a multi-tiered analytical framework that accounts for the physical computing elements necessarily present in all digital music making systems, we can further understand and appreciate the intricacies of digital music performance practice and culture.

I would like to dedicate this thesis to my wife and daughters. Thank you.

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Chapter One

Introduction: A View of Digital Technology

The influence digital technology has had in musical performance over the last few decades has been, in a word, extensive. Digital technology has not only made access to various musical resources much easier but has enabled a new mode of musical performance. Musicians can now, with little effort, access repertoire, pedagogy, criticism, and dedicated communities of performing musicians from around the world. Furthermore, one can, without much difficulty, disseminate their artistic works and find guidance and instruction by use of this technology. In every way that that digital technology can be used to assist music performers also exists a community willing to provide support. It is this democratization of access to knowledge and artistic works that underpins the potential of digital technology as it assists musicians and, in turn, musical culture. In addition to digital technology having these aforementioned educational and collaborative uses, it is also now utilized and viewed as a musical instrument.

Through the lens of this thesis, digital technology is viewed as a highly personal and supple, almost affable, tool for assisting musicians in expressing musical meaning through performance. I argue that musicians using this technology exclusively for performance can develop a relationship with their machine comparable to that between a virtuoso and their acoustic instrument; a relationship viewed as romantic and meaningful in acoustic performance practices but remains underdeveloped when it comes to digital music performance.[1] Taking into consideration the growing opinion that the personal computer, and the potential of expressive peripheral devices, is very much capable of expressing artistic intent in real-time; this thesis will maintain that the computer should be understood as a musical instrument. However, in digital music performance practices this relationship between musician and instrument, or computer, can be viewed as cold, indolent, and otherwise impersonal. This pessimistic view of digital technology and the subsequent apprehension of understanding computers as musical instruments is not surprising considering our history of accepting new technologies into our lives. On one hand we have a penchant for looking at nascent technologies in an unfavourable light, focused on their perceived shortcomings and in turn creating a distance between human beings and our machines. On the other hand, as in the case of the Internet and social media technologies, we praise and adopt its capabilities virtually immediately to the end that we are unable to carry out our daily communication without it. In the realm of digital music, Brian Belat considers the "current directions in computer technology are integrating the various aspects of music creation and performance into a seamless synergy, and there is no reason to assume that this trend can or should be reversed" (Belat 2003, 312).

Our media ecology evolves with every introduction of a technology able to connect us in new ways or assist us in expressing ideas. Each change in our

[1] This view of the performer-instrument relationship can be observed in many works of fiction, academic texts, and is tacit throughout the discourse.

media landscape is often accompanied by negative criticism, apprehensiveness, and in some cases explicit contempt. If we examine our inceptive judgments of past technologies that have significantly changed our lives, and in turn our culture, we see a pattern of initially lambasting their place or use in society. For example, the establishment of the telegraph as a near immediate mode of communication over long distances was at the outset considered mysterious and unnatural. In an attempt to explain its capabilities to the public at large, the telegraph was first framed as a medium able to connect two souls (Peters 1999, 94-95). Moreover, the popular conception of telegraph offices at their outset can be seen through early depictions illustrating telegraph offices as inhabited with the undead. We now view these interpretations of the telegraph as naive and outrageous. Yet, however antiquated this technology might be viewed presently, its introduction marked a seismic shift in our understanding of communication and our larger social environment.

Another example of this initial negative perception can be seen in one of the first commercially manufactured machines capable of playing recorded sound. The phonograph, and its European counterpart the gramophone, had a similarly macabre emergence. Marketed as a means of "embalming" the voices of the living as a means of preservation, this device was portrayed in a ghastly manner focused on the mortality of the consumer and thus the general public feared its recording ability (Sterne 2003, 297). Albeit these historic perspectives do not relate directly to performing with musical instruments, they speak to our cynical attitudes of accepting new technology into our lives by way of a lack of understanding.

Understanding Digital Musical Performance

Before personal computers and other electronic components became both affordable and capable of handling multiple computationally expensive processes simultaneously, very few musicians were able to fabricate or configure unique systems capable of performing music in real-time. The turn of the twenty-first century has seen a substantial increase in the number of musicians performing in digital music genres and developing novel methods of interacting musically with digital technology. Performers of digital music are now able to more easily connect digital musical processes to sensors that capture bodily movement, a practice commonly referred to as *physical computing* (Igoe and O'Sullivan 2004). This evolving control over musical parameters by way of physical computing has created several key problems when considering interactions with computers as musical gestures. The study of musical gesture analysis can offer insight into this phenomenon of performing music with digital machines. However, most research in this field is thus far focused on standardized acoustic instruments and the notion of musical control via computers is somewhat viewed as devoid of musical gesture characteristics (Jensenius et al. 2010, 16).

This thesis argues that gesture analysis of musical performance with digital musical instruments (DMI) diverges from acoustic instrument gesture analysis due to differences in how the instruments function. However, a meaningful typology of DMI musical gestures, based on acoustic performing practices, could be developed if the analytical framework considered the data capture and mapping strategies necessarily present in all DMIs. This proposed analytical framework offers an examination of performances that utilize methods of music making that diverge from traditional Western performing practices. By understanding the computer as a musical instrument requiring physical input to function, creating an analogue to acoustic instruments, we can better appreciate and critique digital musical performance as it becomes more familiar. Moreover, this framework could be employed in musical performances that occur in both nascent and established genres of electronic music, both of which lack appropriate representation in academic discourse. Where this typology of musical gesture and the analysis of data capture and mapping will inevitably differ from acoustic instrumental performance is in the individuality that occurs through the development of a digital performance system. Despite the unique nature of DMIs, I aim to move this individualized music performance practice further into, what Marc Leman identifies as, one's *action-oriented ontology* (Leman 2010, 134).

One of the most salient aspects of digital musical instrument performance is that the apparatuses allowing this musical practice to exist are continually being improved and thus becoming more capable of sounding meaningful human gesture. This thesis aims to situate the research addressing the intricate and remarkable degree of instrumental control performers gain in the acoustic realm, into the digital. However, the study of digital musical performance at this point in time has met the same fate as popular music once did before it was deemed worthy of academic pursuit. The obscurity of DMI performance is due, at least in part, to what Mark Leman identifies as the need for an "action-oriented ontology" in order to understand, or "have mental access" to, musical gestures. Those that consist both of an "embodied imagination (body image)" and actual skills (body schema)" in order to imagine a musical gesture as a gestalt (134). In other words, the methods used by the digital musician for interacting with their instrument can be confusing.

Leman's application of action-oriented ontology in musical gesture analysis relates directly to the "subject" or "a first-person perspective on gesture." His examination considers musicians solely and his framework excludes one's understanding of an isolated musical gesture within their action-oriented ontology unless they have direct experience with that particular instrument. This thesis considers the boundaries of one's embodied imagination and actual skills within their action-oriented ontology as more fluid and present to some extent in all audiences. Under Leman's definition musical gestures observed by an instrumentalist lie outside of their action-oriented ontology unless they play that particular instrument. However, they possess a *global representation* of sound producing gestures with other instruments.

The concept of action-oriented ontology in this thesis is considered from the perspective of an audience and maintains that all spectators of musical performances possesses an embodied imagination and actual skills with musical gestures to some extent. Although the majority of an audience may not have firsthand experience with the instruments used in performance, virtually all people have performance experience even if, at the very least, it is singing and learning songs as children. Audiences are also phenomenologically aware of the materiality of instruments whether or not they have direct experience interacting musically with them. To a certain extent, all audiences have an innate understanding of how the physical properties of acoustic instruments respond to the interactions of a performer. Furthermore, observed musical gestures reside in the imaginations of audience members regardless of how accurate they lie in relation to the actual skills needed to perform musical gestures with an instrument. Observed musical gestures must reside in an audience's embodied imagination in order to be understood as intentional sound producing actions possible through perceivable physical efforts. While Leman's use of action-oriented ontology is focused on the instrumentalist's experience of performing gestures, it is expanded in my analysis to encompass the experience of observing musical gestures during performance.

It is not the intent of this thesis to deem digital technology, as it pertains to musical performance, as the paragon of interactive possibility or musical expression for that matter. But rather to elucidate the capabilities of DMIs and situate the gestural possibilities of these instruments within an appropriate analytical framework related to the acoustic traditions that preceded it.

Views on Emergent Technology in the Discourse

Twentieth century opinions of emergent technologies, while steeped in wonderment, were often initially pessimistic and critical. Marshall McLuhan, while categorically classifying specific technologies into his “hot vs. cold” dualism, thought the age of electric media, the precursor to the digital age, to be “also the age of the unconscious and of apathy” (McLuhan 1994, 47). Notwithstanding the accuracy of McLuhan’s postulations, his writings elucidate an apprehension of various media and the high technology of the time held by scholars and to some extent the public at large.

In regard to current views of digital technology, we find ourselves between a liberal humanist viewpoint and a sort of digital anxiety (Hayles 1999, 34). We are eager to relate our biological and metaphysical attributes to the mechanisms and structures of digital devices. This notion has been propagated to the extent that the term “wetware” has surfaced as a euphemism for a human brain. Alongside this accepted comparison, we simultaneously resist the notion that a computer can truly and accurately be capable of reproducing the complexities of human thought and activity. In the wake of the famous chess match between grandmaster Gary Kasparov and IBM’s *Deep Blue* and similarly *Watson* on the game show Jeopardy!, Noam Chomsky resists the idea that feats completed by computers should be viewed as analogous to human activity (Schmitt 2011).

In his book, *You Are Not a Gadget*, Jaron Lanier also scrutinizes the popular comparison of the biological processes of the human body to digital technology. Speaking to the capabilities of artificial intelligence, he argues that to create an analogue between the complexity of a human mind and the finite form of a computer is fallacious (Lanier 2010, 32). The author suggests that in doing this we curtail our understanding and appreciation of human potential. This notion is worthy of rumination; we are at odds in our conceptions of digital technology and computer technology in a broader sense. As a means of reaching outward, or as a mode of communication, we've come to understand the digital world as expansive, versatile, and extremely effective in connecting us to social networks. The digital landscape has become indispensable in our daily lives despite criticism such as Lanier's. However, as a mode for introspection or tool for artistic creation, digital technology is often viewed as impersonal, restrictive, or cold.

A view of digital technology helpful in contextualizing this thesis is Timothy Taylor's pragmatic notion of agency in technological forms, in this case electronic technology for music creation, between the disparaging deterministic outlook and the optimism of voluntarism. In Taylor's book, *Strange Sounds: Music, Technology, and Culture*, the author explains:

> I am not rejecting the notions of technological determinism and voluntarism out of hand, but am instead saying that both positions are

> overtotalized and falsely binarized, and that opposing them masks the ways that some sociotechnical systems are more deterministic than others (that never wholly deterministic), that some provide for more voluntarism than others (though never total voluntarism), and that social actors do not have the same experiences with any sociotechnical system (Taylor 2001, 37).

The fluidity Taylor identifies between the boundaries of technological determinism and voluntarism shed light onto similarities DMI musicians share in the relationship to their instrument. Our digital landscape determines, at least to some extent, the interactive and responsive capabilities of digital music making systems. Thus, the sociotechnical system of DMI performance, comprised of creators and audiences, produces commonalities between approaches for musical control. Furthermore, if the performers using digitally exclusive DMIs utilize similar technology; then similar modes of physical manipulation and computational processes with and within DMIs would be found. These historical and contemporary perspectives exemplify our eagerness to extend ourselves by embracing new technology but simultaneously our apprehensiveness to wholeheartedly subsume technologies into our self embodiment; and in turn, our action-oriented ontology.

Digital Technology and Musical Performance

Why is it that computer music performance is perceived as mysterious? If we consider the computer a musical instrument, then the average listener would have more personal experience with that instrument than most acoustic instruments. Most listeners and audiences have a deeper familiarity with the interactive possibilities of a computer than a bassoon. The computer as a musical instrument is enigmatic because the interactions between the musician and their DMI do not generally reside in our action-oriented ontology as those "performing with [this] technology requires players to develop new skills and flexibility" (McNutt 2003, 297). It can be the case in computer music performance that the link between the physical interactions with the instrument and the produced sound is completely absent. As put by Andrew Schloss, a "situation in which cause-and-effect has effectively disappeared, for the first time since music began" (Schloss 2003: 239). The average computer user also lacks a developed familiarity with the software programs or audio processes digital musicians employ within their music making systems. Without ancillary or supportive gestures the sound producing musical gestures with a computer can seem, for the audience, so unexceptional that it would be difficult to differentiate a computer musician triggering musical events using a mouse and keyboard with their computer from checking their email. Additionally, unfamiliar or obscure gestures with custom peripherals employed in a DMI as an alternative means of musical control would not be obvious within an audience's action-oriented ontology of musical gesture, thus contributing to its perplexity.

Until recent years, digital musical performance, although growing in popularity, has been underrepresented in musicological discourse save for a few pioneers and advocates. There is much research focused on the technologies that DMI performers utilize and electronic music, however little has been written on the gestural aspects of this performing practice and the strategies these musicians employ in the configuration of their instrument.

Interactive Possibilities With Digital Interfaces

The possibilities for interacting musically with computers have changed drastically with the widespread availability of music specific peripherals and other hardware capable of being mapped to musical parameters. As the popularity of digital music making grew, so did the need for expressive musical interfaces.

> When inventing acoustical instruments, designers have to find the best compromise between the abilities of the human body and the physical constraints involved in sound production. The gestures used on acoustical instruments depend strongly on the physics of the instrument. In digital musical instruments, sounds can be generated without any physical constraints: the designers of instruments of this kind are free to choose whatever gestures they want and how they want these gestures to link up with the sounds produced (Arfib et al. 2005, 125-126).

Above, the authors speak to the dynamic nature of digital interfaces for music creation and the flexibility that exists in assigning musical functions to physical gestures. It is important to note that how we interact with a device or interface and the computational processes that produce the resultant sound are equally significant.

Although computer-driven musical research and development has evolved alongside the progression of computer technology since its inception, most of the pioneering research occurred in academic and laboratory settings (e.g. NRC, IRCAM, STEIM, Manhattan Research Inc.). What has changed drastically in the last decade is that prototyping materials and adaptable hardware and electronic components have become readily available and, perhaps more importantly, affordable. This technology has sparked an expansive community of individuals willing to collaborate, instruct, and otherwise support a growing culture of computer musicians. Currently there exist a myriad of sensors adept at outputting high resolution data and have proven proficient in capturing the most minute of physical movements. The potential in the inclusion of these implements for musical outcomes is nothing short of revolutionary for our relationship with computers. The utilization of these types of sensors for computer music interactivity has heightened the status of the computer as a musical instrument. The gestural vocabulary of a DMI is preconceived in the design of the interface before the performer internalizes playing the instrument physically. DMI designers may decide to develop new gestures or include gestures they may have acquired from performing practices they may be familiar with, or both.

Interfacing digital technology to invent musical instruments has created a musical practice deviating from acoustic instrumental performance practices. Because designing musical instruments using digital technology removes "physical dependencies, all previous restrictions regarding the split in the controller-generator chain are relaxed in the design of digital instruments. Any input can be now linked to any output, and both components can offer a virtually infinite number of possibilities (Jordà 2004). Notwithstanding, current frameworks employed in the analysis of acoustic musical gestures are applicable to purely digital DMIs if adapted to account for design elements specific to these instruments; namely, gesture capture and data mapping. It is my goal to situate this divergent performing practice within a larger musical tradition and rhetoric in order to expose its intricacies. The pivotal characteristics of DMIs that set them apart from acoustic instruments lie within the digital processes that occur during instrumental excitation. In comparison, the sound producing qualities of acoustic instruments are inextricably bound to their physical properties while DMI rely on generated data and its implementation by the performer. The generative and manipulative capability of a DMI is determined by the data produced by the instrument and how the data is assigned to musical parameters. The necessity of mapping generated data is a key component in DMI design and analyzing gestures with these instruments requires distinct considerations. Each interaction with a DMI begins as an idea before it can be an articulated musical gesture.

Acoustic and Digital Instruments: A Comparison

As obvious as the similarities between acoustic and digital musical instruments can appear, the construction of these new devices have phenomenological characteristics not possible in acoustic instruments. The sound an acoustic instrument produces relies on its material. These established instruments could be understood as static artifacts whose qualities must be learned by the player to proceed in sounding the desired musical material. Where DMIs are dissimilar resides in the configuration of how musical sound is produced. A DMI captures the gestures and interactions of the performer's movements and translates these gestures into data. The data must be assigned, at the performer's discretion, to musical parameters via sound production and manipulation software or other sound producing devices. Although the interactions with DMIs are bound to the capabilities of the electronic components used, the resultant sound-producing processes are free to be assigned in the manner sought by the performer. Thus, a new relationship between a musician and their instrument is possible through this dynamic approach to musical performance. A DMI practitioner, through the lens of bricolage, interacts with sound producing interfaces in ways simply not possible with traditional acoustic instruments.

In order to analyze the intricacies of musical interactions with digital technology, an expanded typology of musical gesture must be developed. In addition to the typologies developed in the field of musical gesture analysis for acoustic performing practices, the gesture analysis of digital or computer music performers must also account for the components of DMIs not present in their acoustic compeers.

This new relationship between computer musicians and their self-developed instruments is incumbent on two phenomena: gesture capture and data mapping. First, DMIs must capture data generated through physical interaction. However, the interactivity required of a DMI can differ greatly from instrument to instrument. The interactions required by a performer can be as simple depressing pushbuttons, as customary as playing a keyboard instrument that transmits MIDI data, or as unconventional as collecting biometric data from the performer or audience. While full of musical potential, DMI performance gestures with alternate gestural controllers remain silent without provision in a sound producing system. The data must be mapped to sound producing software for the instrument to function. Atypical of most other musical performance practices, musicians working in this idiom have an unprecedented amount of control of how they prototype and perform with their instrument.

Support and Community: The Culture of Digital Musical Performance

Notwithstanding that digital music performance currently lacks a history of comparable length to acoustic performance practices, standardized instruments, and canonic pedagogy, it has produced an extensive community of devoted practitioners, enthusiasts, and virtuosos. It should be noted that Jennifer Butler has composed 10 etudes for an unspecified DMI, however DMI repertoire for instruction is scarce (Butler 2008). Working in the digital realm, most DMI performers are assumedly somewhat computer savvy and would in turn have little trouble accessing the expansive online community pursuing this musical idiom. Interestingly, the tools used to create DMIs, or the instrument itself, is that which gives the musician access to the knowledge necessary in order to develop their instrument and performance.

In contrast to acoustic instrumentalists, digital music performers take an individual approach in DMI creation and performance. Each DMI is specific to the performer and thus, this musical practice is largely unable to standardize the interactivity and gestures that may occur between the musician and their instrument, or machine. In other words, unless a computer musician shares all of the elements and organization of their instrument with another computer musician, their instrument is unique. Acoustic instrumentalists undoubtedly benefit from sharing identical biomechanical and physical attributes of their instrumental practice with others. Acoustic instrumentalists have the opportunity to study in various academic and non-academic settings with an instructor familiar with not only the technical performing practice but also the cultural aspects and history of their instrument. Additionally, there exist extensive pedagogical and canonic repertoires, among other resources, for established instrumental practices that are evidently missing from such a nascent practice as digital musical instrumental performance.

Terminology

In a musical culture as recent as DMI performance there exists a need to employ the terminology of established disciplines. However, many of these terms rooted in other musical practices encapsulate inexact meanings for the specific practice this thesis addresses. I refer to digital musical instruments or DMIs, as configurations of software and hardware elements used together to create digital music specifically. A digital musical instrument, in the context of this thesis, must include a physical interface intended to generate data that is interpreted by a software counterpart to create musical sound. A DMI under this scope will exclude instruments that have an acoustic instrumental component. Furthermore, my analysis will account for DMIs that only utilize a physical interface that could be characterized as an alternate controller according to Miranda and Wanderley's typology outlined in the following chapters. The term "alternate" - or alternative - as it pertains to DMI configuration is similarly utilized by Dan Overholt et al. as belonging to the "three basic groups of gestural controllers for music: (1) instrument-simulating and instrument-inspired controllers, (2) augmented instruments capturing either traditional or extended techniques, and (3) alternative interfaces, with the subcategories of "touch," "non-contact," wearable," and "borrowed"" (Overholt et al. 2009, 70). Making these distinctions in DMI configurations is extremely important as the design of the instrument ultimately prescribes the gestural vocabulary available to the performer.

The adjectives digital, computer, electronic, electroacoustic, acousmatic, etc. as they pertain to music or musicians refer to distinct musical histories and compositional philosophies. It is my goal to utilize the terms above in their most accurate socio-cultural contexts. There are many musicians that extend or augment their acoustic instruments by incorporating computers or other digital attributes. The performance practices used when playing augmented instruments, instrument-like, or instrument-inspired controllers largely draw from existing acoustic instrument performing practices and lie beyond the scope of my analysis. These partially digital, partially acoustic instruments have differing restraints and advantages for gestural interactivity as compared to alternate, or digitally exclusive, musical instruments. Lastly, my analytical framework focuses on DMIs that can be programmed, configured and customized to an extent not possible by using commercial digital music interfaces exclusively.

> Most computer instruments in use are those provided by the commercial music industry. Their inadequacy has been obvious from the start; emphasizing rather than narrowing the separation of the musician from the sound (Ryan 1991, 6).

Although commercial interfaces for the control of digital music have greatly improved since Ryan's review of digital music technology in the early 1990's, most manufactured today are designed for performance, recording, or control of specific music software. For example, AKAI's APC20/40 and Novation's LaunchPad are "designed specifically for Ableton Live" (Ableton 2013). In addition to the Ableton Live specific controllers above, many digital music software programs, including Ableton Live, attempt to achieve "instant mapping" for dozens of other popular controllers. Some performers utilize commercially manufactured interfaces or *automapping* software as a central component of their DMI or their instrument might be entirely comprised of commercial products. Those musicians that use only commercial products can indeed acquire a high degree of mastery and intimacy with the DMI they've developed. However, I argue that DMIs constructed from adaptable modules, that when assembled become a complex and original performance system, can prove a more fertile ground for developing a more interesting virtuosic relationship with a computer. It is the painstaking process of connecting every gestural interaction to a musical parameter when constructing a modular DMI that gives the performer a more intimate understanding of their instrument.

DMI culture has redrawn the boundaries of what constitutes a musical instrument and has expanded embodied musical gestures. This practice has also animated a shift in musical thought and the processes involved in producing musical works. As compared to acoustic instrumental and conventional compositional techniques, the digital music practice can be viewed as distinct through the inclusion of technology that redefines the relationship between the musician and their tools. Finally, this new practice has also expanded the relationship between human beings and computers. Through the lens of digital music performance, computers can be seen as dynamic devices that are continually becoming more capable of capturing gesture and expressing artistic intent in a musically meaningful way.

Chapter Outline

The second chapter examines the hardware and aspects of DMIs and situates physical computing as an instrumental tool within this musical practice. The process of DMI configuration is framed within the context of *bricolage* and compositional methods established within the last century. I outline several approaches often employed in designing DMIs as well as a comparisons of function and design with acoustic instruments. The second chapter also outlines preexisting typologies of DMIs and the discourse examining development and performance with DMIs while providing examples of digital instruments significant in this evolving musical practice.

Chapter three explores the software and physical computing elements necessarily present in all music making systems using digital technology. This chapter offers a literature review and aggregate typology of the methods used in capturing physical gestures by performers and their mapping to musical parameters within a DMI. A comparison to acoustic instruments is provided in an attempt to elucidate this novel method of musical control and illustrates some of the problems that face designers and performers in this musical culture. Lastly, this chapter offers an explanation of how Michel Waisvisz's instrument, *The Hands,* is configured and stands as an example of the interactive possibilities capable of a highly developed DMI.

In chapter four I explain the impetus for undertaking this thesis and my personal conversation with Waisvisz about his instrument. This chapter also provides an aggregate typology of acoustical music gestures and a proposed expansion that takes into account the biomechanical and computational aspects specific to performing with a DMI. I explicate the philosophical and practical dimensions of this phenomenologically rich performance practice and explore the processes present when developing an intricate relationship with digital instruments. I apply an aggregate typology of musical gesture to Waisvisz's performance style to prove that an expanded action-oriented ontology is possible through a heightened understanding of DMI functionality. This chapter closes with ruminations that consider the perspective of audiences and the problems they face in the observation and understanding of physical gestures and their relationship to musical sound during DMI performances.

Finally, I conclude by revisiting the notion of the DMI designer as a bricoleur and the affect the *parametrical approach* in composition has had on this performing practice. I argue that DMI performance has animated a shift in psychoacoustics and musical thought. Furthermore, I outline how recent trends in digital music making tools might influence future generations of digital musicians and bring DMI performance practice further within the action-oriented ontology of audiences.

Chapter Two

Bricolage in DMI Performance Practice

Building It Myself: Deviant Methods of Building Instruments

Electronic music creation deviates from traditional acoustic compositional methods as it relies on digital technology for its production. Claude Lévi-Strauss' critique of "bricolage" in his book *The Savage Mind* is helpful in understanding the phenomenon of system building for electronic music creation (Lévi-Strauss 1966). The French term "bricolage", or "bricoleur" (someone who practices bricolage), does not have an exact analogue in English. The closest idiom that illustrates the meaning of this term might be "Jack-of-all-trades" or "DIYer" (Do-It-Yourself). However, these English expressions imply that the practitioner does not exhibit expertise in the skills they possess. The bricoleur, as explicated by Lévi-Strauss, "is adept at performing a large number of diverse tasks" (Lévi-Strauss 1966, 17). Moreover, the bricoleur also "works with his hands and uses devious means compared to those of a craftsman" (16). When a digital musician fabricates part of or their entire performance system, they become a digital music bricoleur. The digital music bricoleur must acquire ancillary skills distinct of those traditionally present in musicians in order to successfully develop an operational system. The electronic music bricoleur combines diverse electronic elements in unpredictable configurations, often creating new methods of representing and interacting with musical material. The DMI musician, seen through the lens of bricolage, can be understood as part composer, performer, and designer by creating a digital system intended solely for the purpose of performing music.

Lévi-Strauss' examination of bricolage is contrasted with the activities of the scientist or engineer. These two approaches to building or creating things differ in that "the engineer is always trying to make his way out of and go beyond the constraints imposed by a particular state of civilization while the 'bricoleur' by inclination or necessity always remains within them" (19). Timothy D. Taylor has also employed the use of Lévi-Strauss' comparison of the bricoleur versus the engineer in his book *Strange Sounds: Music, Technology & Culture*. Taylor uses this comparison to illustrate the differences in compositional approach of traditional composers and musique concrète (among the first established methods of music making that used electric technology) composers.

> The musique concrète composer moves just as a bricoleur does: from materials at hand to a structure, whereas composers of "ordinary music" - just like Lévi-Strauss' scientists and engineers - begin with an abstract concept and move toward its material realization (Taylor 2001, 59).

Taylor's comparison illuminates the nature of this deviant compositional practice in Western music surfacing as an act of bricolage. This new compositional practice and musical aesthetic was made possible only through the incorporation of unconventional technology into musical practice. Taylor views musique concrète composers as bricoleurs because they collect and manipulate everyday sounds that occur in their immediate environment in order to build larger musical structures. The manipulated sounds maintain characteristics of their original source while are simultaneously recontextualized and accrue additional musical meaning.

Taylor’s comparison focuses on the formal and aesthetic structures that resulted from using only electric technologies for music composition. It remains implicit within Taylor’s analysis that musique concrète composers also configured their own music making systems in order to produce their compositions. In other words, not only can bricolage be located in the compositional methods of musique concrète composers, but also in their utilization of music technology in subversive ways in order to arrive at new musical aesthetics. As technology advanced throughout the latter half of the twentieth century, and was further incorporated into compositional methods, the number of possible systems expanded accordingly. Presently, the bricolage approach for creating musical systems allows for a staggering number of electric, electronic, and or digital configurations.

Bricolage as a contemporary compositional practice for fabricating musical instruments continues to grow in its interactive potential for musical expression. This is due to the fact that every element connected to the digital system has the potential to interact with and influence the behavior of the system. Moreover, the number of musicians adopting this process is also growing alongside dedicated communities devoted to exchanging information helpful to practitioners.

> It is now common for electronic musicians working with code or development environments such as Max/MSP to publicly release programs that embody aspects of their own compositional and performance practice (Bown et al. 2009, 192).

With each possible element able to be included within a digital music system exists a community both in many major urban centres and online, centred on its use and development. As electronic musicians not only gain access to an expanding inventory of digital technology but also to strategies for implementation, the potential for personalization within a system has greatly heightened. Lévi-Strauss states that when the bricoleur builds a system, "the decision as to what to put in each place also depends on the possibility of putting a different element there instead, so that each choice which is made will involve a complete reorganization of the structure" (Lévi-Strauss 1966, 19). This speaks to the vast number of possibilities for bricolaged digital music systems.

Contemplating digital music creation as occurring through systems sheds light onto the intricacies of self-fabricated instruments, the skills necessary for their development, and the musical culture in general. Within a bricolaged structure "the possibilities always remain limited by the particular history of each piece and by those of its features which are already determined by the use for which it was originally intended or the modifications it has undergone for other purposes" (19). Therefore, it is through an investigation of the types of systems and their interactive potential that will elucidate how digital music creation differs from traditional performance and compositional practices. When we acknowledge the digital system building electronic musician as a *bricoleur*, the complexity inherent in this musical practice becomes apparent. When creating a digital music system each subsequent inclusion of an element may animate a complete reorganization of that system. Also, each system becomes unique to a particular musician making it difficult to locate an objective commonality in how electronic musicians materialize their artistic vision. This explains the difficulty in fully understanding the implications of computers and digital technology in this musical practice.

Electronic versus Acoustic Instrumental Practices

The phenomenon of digital music bricolage creates a musical system, or instrument, that is unique to an individual. The conventional compositional methods of classical, jazz, and popular music genres alike utilize standardized instruments and convey musical information crucial for its performance through music notation and oral communication. These traditional methods of formulating musical ideas and organizing their production often require multiple individuals to realize a musical work in order for the composer to be able to hear an accurate rendition of their artistic vision.

There exists flexibility when composing in the digital realm that negates the need for multiple musicians playing simultaneously to aurally review a composition during the compositional process. Electronic musicians, by working in software environments, can immediately listen to a composition at any stage in the creative process and make artistic decisions without the need for an ensemble to rehearse a particular piece or passage. The digital music system that an electronic musician employs directly influences the compositional choices made and the subsequent organization of musical material. Understanding how a digital music system functions and the types of human interaction needed to produce sound is further complicated when electronic musicians fabricate components of these systems or entire systems.

In acoustic instrumental practices there are a variety of standardizing elements by which we learn, teach, and understand a particular instrument and its history. First, there exist instrumental standards of how a certain instrument should react and behave if played properly. In compositions intended for pedagogy, the composer may consider the technical proficiency of the musicians they are composing for. In turn, their artistic intent would be guided by an expectation of what a particular ensemble or soloist is capable of performing at a certain skill level. For all orchestral instruments there are both student and professional models of varying qualities and some types of instruments come in scaled models for teaching young players (e.g. 1/2 or 3/4 sized string instruments). With the standardization of the behavioral characteristics of an instrument come expectations from the musician regarding the interactive nature of that instrument. In acoustic instrumental practices there are conventions defining the formal interactions between the musician and their instrument. This is to say how a particular instrument should sound, respond, perform, etc. In digital music practices, no two self-configured instruments can be assumed to be identical and the outcomes of captured musical gesture may also be unique.

> The acoustic instrument is material and developed from bottom-up exploration of the acoustic properties of the materials used...The digital

> instrument is theoretical and developed from a largely top-down methodology. In order to make the instrument, we need to know precisely the programming language, the DSP theory, the synthesis theory, generative algorithms and musical theory, and have a good knowledge of Human Computer Interaction (Magnusson 2009, 174).

DMI bricolage dissolves the relationship between the musician and their instrument as compared to acoustic performing practices. By virtue of the fact that a digital music bricoleur's system represents a culmination of acquired knowledge, there is an inherent interdisciplinarity within this instrumental practice. On the other hand, the formal avenues in which the acoustic instrumentalist gains proficiency in their tradition are more restrictive with respect to the variety of knowledge considered applicable to their particular performing practice. "In the curriculum of the conservatory or the university music program, the study of the techniques of instrumental performance is kept separate from the study of theory, composition, and, to a lesser extent, even history" (Théberge 1997, 161).

The crux of the matter is that, at the writing of this thesis, a standardized instrumental technique has not been established across DMI performance practices. However, a typology of possible and common gestural vocabularies can be observed. It is important to consider the various fields of knowledge exhibited by the digital music bricoleur and how this changes the relationship between a musician and instrument. The digital music bricoleur has an intimate knowledge of what makes their instrument operate, and how previous iterations of prototypes fell short. "Designing new instruments ultimately involves a change in the relationship between performed actions and perceived responses on the part of both performer and listener" (Essl and O'Modhrain 2006, 287). While acoustic instrumentalists gain mastery though prolonged immediate contact with their instrument, the digital music bricoleur gains mastery with their system beginning with the conceptualization, fabrication, and designing the interactivity of their instrument before moving to gain proficiency through practicing their DMI.

In David Wessel and Matthew Wright's article, "Problems and Prospects for Intimate Musical Control of Computers", they explore several performance aspects of current digital music systems (Wessel and Wright 2002, 11-22). Bricolaged digital music systems can require varying degrees of required interaction from the performer for their operation. Developing a responsive, low-latency, and reliable method of capturing and assigning physically generated data is of utmost concern. The above authors "note that almost all traditional acoustic instruments afford (and require) continuous control, and, for the most part, it is this continuous control that makes them expressive" (13). In order for digital music systems to be capable of gestural expression, the system must be configured to be able to quickly and efficiently generate, transmit, and assign data to musical parameters.

In Summary of DMI Design

Digital music bricolage has created a shift in compositional and performance methodology and has influenced the ways in which we can create and experience musical sound. The configuration of a DMI dictates the sound created and thusly the digital system itself accrues a musical quality.

> Composers do not represent their ideas in a uniform manner and therefore any flexible representational system demands a strong user-defined link between the material and its symbols of signification (Vaughan 1994, 127).

The system itself becomes an agent responsible for the organization and aesthetic of the music produced. When first learning to perform with a self-configured DMI, the possibilities can be intimidating. The DMI bricoleur must move to standardize aspects of their own approach to music making as continually adapting one's "instrument demands constant adaptation and memorization from the musician. The mental load of dealing with a constantly changing system will never allow a musician to internalize the system and achieve efficiency and effectiveness" (Vertegaal et al. 1996). To what extent the system becomes responsible for affecting each attribute of the music is a matter of design and interactivity.

Acoustic Instrument Design History and the Standardization of Performance Culture

Traditional orchestral musical instrument design has to a large extent remained unchanged since the mid-19th century (Bijsterveld and Schulp 2004, 650). This standardization and stabilization of acoustic instrument design for approximately a century and a half has allowed for the development of standardized performing and pedagogical practices. It is a fascinating idea that the standardization of an instrumental performing practice is predicated on the stability of instrumental design, an aspect difficult to locate in digital instrumental performance. Many orchestral instruments, and to a lesser extent more recent instruments such as the drum kit or saxophone, have histories of development and have seen numerous advances and iterations that, according to Bijsterveld and Schulp, eventually halted in the mid-19th century.

Orchestral instruments possess a history long enough that we see many ensembles interested in preserving past performing practices, such as “period instrument” ensembles. For example, the Tafelmusik Baroque Orchestra and Chamber Choir based in Toronto, Ontario exclusively perform the repertoire of the baroque era on instruments either constructed in that historical period or those recently manufactured but conform to the building practices of that era in attempt to recreate the timbre of music characteristic of that time (Tafelmusik 2012). Many performing practices developed throughout music history have seen a resurgence in present day music ensembles. The performing practices of modern instruments popularized by newer musical genres, although lacking a history comparable in length to “classical” practices, have become standardized and in turn so has their gestural vocabulary. In contrast to acoustic instruments, DMI gestures must be conceived and configured even if they resemble or emulate gestures belonging to, or distinct of, an acoustic performance practice.

Physical Computing and Musical Control

The internal, external, and symbolic differentiations in the immersive category of alternate gestural controllers outlined above do not pertain to the overarching organization of the physical components of a DMI but rather to the virtual or intangible elements of its functionality. The data generated by a DMI does not contain inherent meaning without first being mapped to a musical process within the software. Alternate gestural controllers, lacking an intentional sonorous element, operate entirely using a technique referred to as *physical computing*. This is now a widespread practice but was once isolated within the domain of engineering. There are now many low cost (≈$25 USD) and open source hardware development platforms that have democratized the fabrication of interactive objects. Massimo Banzi, a founder of the widely used Arduino platform, explains this method of hardware development as “the design of interactive objects that can communicate with human beings using sensors and actuators controlled by a behavior implemented as software running inside of a microcontroller” (Banzi 2009, 3). The outcomes of physical computing are astonishingly ubiquitous in the modern world. From traffic lights to thermostats, our urban surroundings react to agents either through direct interaction or by the indirect monitoring of tangible systems or environmental fluctuations. Some of the most familiar examples of this in our digital media ecology are the computer mouse and keyboard. The user navigates and controls various computational processes via standardized physical gestures and predictable computer behaviors. Although the simplicity of the two axis control of the computer mouse and the familiarity of the QWERTY have stood the test of time, these interactive (or HID) devices are incredibly archaic in their ability to capture the intricacies of human movement for computer control. In his book, *Gramophone, Film, Typewriter*, Friedrich Kittler argues that the limitations of fixed technological forms proves a resolute technological determinism, this being especially true of digital technology (Kittler 1999). There lies a degree of truth in the view that rigid technological structures for human-computer interaction restrict the potential expressivity of an interactive system. I maintain that utilizing disparate components for creating larger digital systems for artistic and expressive control of computers operate within a finite number of possible configurations. The flexibility and unpredictable characteristic of technological research and development give way to a musical culture that will continually allow more accurate and capable means of controlling digital processes. The technological voluntarism afforded to DMI designers and performers opposes Kittler's conclusion that "programmability replaces free will" (Kittler 1999, 259). This is not to say that DMI design and performance dissolves the boundaries of determinism, but the combination of adaptive hardware and software reinforces this musical practice as a valuable and phenomenologically abundant culture.

Open-Hardware: Developing Interactivity

As more capable hardware components became more affordable and readily available, the solutions possible for creating DMIs also expanded. The types of hardware and software that best describe these new methods for musical control are those that can be described as “open”. An example of an open-hardware solution for creating DMIs is the “Arduino” hardware platform. The Arduino is an open-source microcontroller that can be used to prototype DMIs by making it easy to connect multiple sensors to a computer via USB. Being an open source project, the schematics are provided on the Arduino website so that one could build this microcontroller. Alternately, a preassembled version on a PCB (printed circuit board) about the size of a credit card and preloaded with the software needed can be purchased from their website. At the heart of the device is an Amtel AVR chip that must be programmed to carry out sets of instructions predetermined by the user.

The Arduino website offers a publicly editable wiki that features hundreds of user submitted projects, many with a musical focus. Web communities, such as this one, allow digital musicians access to a tremendous amount of design and fabrication approaches and a means to communicate with other developers regarding the merits and faults they may have discovered in the development of their posted project. Another DMI development project using an Arduino board is the Arduinome: Arduino Monome Project. The Arduinome project, and more recently the similar Chronome, set out to give the digital music community access to the sought after open-source Monome device by utilizing the Arduino as the microcontroller for the device in lieu of the custom PCB developed by Brain Crabtree of the Monome company. Being a small company, and due to the success of the Monome, the number of devices produced could not nearly meet the market demand. Those behind the Arduinome, with support from the Monome company themselves, made available a parts list, the Arduino code needed, and detailed instructions on how to build one's own device. The reciprocity witnessed in the information exchange for DMI creation is noteworthy. This community supports individuals in all stages of DMI design by helping people develop the ancillary skills needed, such as soldering and electrical theory, to successfully conceive and produce an instrument of their own.

In addition to the Arduino there are several other widely used microcontrollers each with a user community supporting their implementation in various projects. Picaxe, BASIC Stamp, and the Netduino are examples of different microcontrollers, each using different programming languages, that are capable of creating interactivity between digital systems and humans. Namely, the ability to connect data captured by sensors in the physical world to a digital environment in which that data could be assigned to musical parameters.

The artistic decisions and design considerations made in developing the interactive elements of a DMI reflect the performance identity of the instrumentalist. This is to say how they visualize themselves manipulating their instrument within a performance space and context. The digital musician contemplates physical computing and to what extent their body will play in the gestures required to produce and manipulate sound. As contrasted with learning to play acoustic instruments, developing aptitude with a DMI is significantly dissimilar. The relationship between a musician and their acoustic instrument is most often founded on an established performance culture. What this provides for a musician is incredibly extensive. Presuming an acoustic instrumentalist learns their instrument through established pedagogy, they inherit many facets of performance culture including etiquette, familiarity with canonical repertoire, expected behavioral characteristics of the instrument and, most importantly in this context, the gestural vocabulary needed.

The gestural vocabulary of established performing practices is not only fine-tuned to produce the best sound possible, but also possesses ergonomic considerations particularly in efficiency of movement and preventing injury. Contrastingly, all gestural requirements of a DMI are built from the ground up, as "each link between performer and computer has to be invented before anything can be played" (Ryan 1991, 5). Within the relationship between captured musical gestures and their mappings to musical outcomes lies the difficulty for audiences in understanding, and in turn fully appreciating, DMI performance.

Under this light, in comparison to playing digital instruments, it is not my intention to frame acoustic instrumental performing practices as static. The progression of acoustic performance has undergone many innovative advances in recent history. For example, there have been new pedagogical tools for extended techniques on various orchestral instruments expanding the sonorous potential for composers and performers. Also, there have been innovations in prepared piano techniques through the works of John Cage. In regards to music notation, composers are finding new ways in conveying musical information that challenge acoustic instrumentalists to redefine their relationship with their instruments. These innovations exist as minute deviations in an existing performance practice, such as the Bartok pizzicato, a technique where the string player pulls the string up far enough that the excited string will physically strike the fingerboard when released. Expanded notation can also be seen in complete musical pieces that use unconventional notation exist such as in Krzysztof Penderecki's, *Threnody for the Victims of Hiroshima.*

It is important to iterate that acoustic traditions are not without their own innovators and subversive practitioners that expand musical performance techniques and push the art into new aesthetics. Developing an accurate method of analyzing DMI musical gestures with alternate gestural controllers must occur within an interdisciplinary framework. A heightened understanding of the hardware attributes of a DMI (including physical computing strategies for data capture), current approaches in design, and the data mapping of the physical manipulation of digital instruments helps expand the action-oriented ontology of the viewer of a DMI performance.

Problem of Continuity in DMI culture

Their unique and personalized nature makes DMIs difficult to delineate without the insight of the designer/performer. In his article “Who Will Turn the Knobs When I Die?” Bruce Pennycock explores this notion and addresses some of the issues distinct of digital music performance. Through his personal experience as a performer and composer in this musical idiom, he comments on the difficulty many experience regarding the preservation of an interface used for a particular composition:

> for the most part the knobs for my pieces and for many other interactive compositions by my colleagues simply do not work anymore (Pennycock 2008, 207).

As digital music instrumentalists reiterate their interfaces and/or approaches to configuring and mapping their gestures to musical parameters the earlier iterations can, for example, end up abandoned in favour of superior digital components. Pennycock also speaks to the individual nature of DMI development and the inherent difficulties in effectively passing on performance systems to other performers:

> All but a few of the interactive pieces I composed over a 15-year period required my personal intervention at each and every performance. Thus, the question: who will turn the knobs when I die (199)?

Such is the case with the late Michel Waisvisz’s instrument *The Hands*. After his passing in 2008 his instrument, thus far, has become more so an emblem of his life’s work rather than a static form to be directly modeled by other practitioners. Waisvisz’s approach to controlling digital musical processes by way of physical computing inspired many practitioners. However, the manufacturing of exact replicas of *The Hands* as a commercial device seems unlikely. The notion of the *learnability* of a gestural controller, as described by Wanderley and Orio, speaks to the pragmatic aspects of learning how to play an instrument that uses unconventional gesture vocabularies (Wanderley and Orio 2002, 71). A DMI performer, who has not fabricated their instrument, must first learn to play the instrument prior to performing in a concert setting. It is improbable that a DMI instrumentalist would acquire, let alone gain proficiency with, a legacy instrument such as *The Hands* for instrumental performance. However, in the case of augmented instruments this seems more likely. In the case of Palcacio-Quintin's *Hyper-Flute,* it is her hope that others learn to play her DMI (Palcacio-Quintin 2008). The crux of DMI performance lies not within static instrumental forms but rather in the process and development of creating digital systems capable of expressing artistic intent. This essential attribute of DMI performance must be at the forefront of an audience's engagement in order to thoroughly appreciate this musical culture.

Michel Waisvisz's The Hands: An Approach for Acute Digital Musical Control

The development of Michel Waisvisz's alternate gestural controller took place over two decades and saw multiple revisions of both the physical and digital components. Since his death in 2008, *The Hands* have become an artifact of not only a community's dedication to digital musical performance but of human ingenuity and innovation. Waisvisz's philosophy and practice of musical creation using new technology pushed the boundaries of the aesthetics of digital art music and the performance practice of DMIs. *The Hands* helped set the precedent for accurately controlling computer music software using physical computing techniques. His instrument effectively broadened digital music performance and the sonic palette musicians have come to consider aurally engaging.

The components of his instrument interact with one another sequentially. Firstly, the various sensors on *The Hands* capture the performer's gestures with the instrument. The sensory data produced by playing the instrument is transmitted by a microcontroller clocking the state of the sensors, i.e. the STEIM conceived microcontroller called the SensorLab, which continuously reports the state of all sensors in the instrument. The sensor data is then converted to MIDI data by the microcontroller and passed to software.

The SensorLab, and later the JunXionBoard, were hardware products developed by STEIM and have since been discontinued. These electronic tools were STEIM's solution for DMI developers allowing for easy connection of sensors to computer software. With the emergence of low-cost microcontrollers such as the Arduino platform and Picaxe, coupled with the cost of manufacturing, STEIM has discontinued sale of these products but allows their artists in residence access to these development tools.[2] The SensorLab was used in the early iterations of *The Hands* and was capable of translating gestural data into

[2] During an Artistic Residency at STEIM that I held during the spring of 2007, I was granted access to these tools for personal research and development.

outputted MIDI data in real-time. Comparatively, the JunXionBoard used alongside the JunXion software translates serial data produced by sensors into music specific data (MIDI or OSC). The latter of STEIM's DMI hardware platforms are typical of most other DMIs, leaving it to the software components to translate sensory data into music specific data protocols. The MIDI protocol is the most widely adapted but more recently digital musicians have begun to use the more capable protocol, Open Sound Control (OSC). The JunXion software developed by STEIM is a highly capable and versatile software tool for translating many different types of digital data into these aforementioned music specific data protocols.

The Hands' outputted MIDI data was routed into a software program, also developed under the artistic direction of Waisvisz at STEIM, called "LiSa", an abbreviation for *Live Sampler*. Within this music creation environment the user is free to assign the incoming data to whichever musical parameters they desire. Using LiSa, a performer is able to load and manipulate audio material stored in audio buffers, or what STEIM refers to as "sound fields". The end-user can record new audio material into the buffer in real-time and playback and manipulate the stored musical material using multiple *playheads*. In other words, the performer has the ability to voice several points of the buffer simultaneously by placing playheads at various locations within the buffer. Audio effects can also be applied to the playheads individually or in groups in real-time allowing further control of the sound. In essence, the performer is simultaneously "playing" the physical instrument and the software environment as a unified system. The end of the digital system of *The Hands*, or any DMI, is a loudspeaker sounding the digital audio processes for an audience.

In DMIs, such as Waisvisz's, the gestural interactions and their resultant musical function are predetermined by the developer of a DMI. From the conception of the instrument to its use in performance, each gesture must be designed and implemented to the sound producing processes. In the case of *The Hands*, although several people were involved in its development, the decisions made in its fabrication were intentional and sought to assist the performer in realizing the imagined musical aesthetic or creative vision of the musician. Waisvisz's *The Hands* is among the most developed examples of how devoted digital music instrumentalists acquire virtuosity and develop a rich relationship with digital technology for the performance of music.

Chapter Three

Gesture: Interfacing Musically With Machines

The impetus for this thesis occurred during an artistic residency I held at STEIM (STudio for Electro-Instrumental Music) in Amsterdam, the Netherlands in the spring of 2007. During this residency at STEIM I had a fantastic opportunity to converse with the Artistic Director at the time, the late Michel Waisvisz, about the DMI he had developed named *The Hands*. The first iteration of the instrument was completed in 1984 however the software and hardware components underwent several revisions over the next couple decades. *The Hands* consist of two interfaces worn over each of the performers hands and are used to control music software developed by Waisvisz and Frank Baldé at STEIM.

Our conversation progressed through my asking a barrage of questions, that he was content to answer, about the physical and computational components of his instrument. He answered my questions in part by performing examples illustrating the various aspects of his instrument over which he had virtuosic facility. As he played his instrument by locating stored musical examples in his laptop by depressing various combinations of buttons, he closed his eyes to remember where he would find the specific stored examples. His laptop screen, placed out of his view, opened window upon window of musical material ready to be sounded and manipulated. Although the laptop is an essential component of Waisvisz's instrument, his virtuosity allowed him to interact with his

DMI with utmost ease and without the need to visually reference the state of his computer. Waisvisz had developed a degree of intimacy with *The Hands* that the operations capable of his DMI were completely internalized. His relationship with not only the physical attributes of his instrument, but the organizational structure and functionality of the computer component was astonishing.

My discussion with Waisvisz had made me more fully understand the construction, configuration, and culture of digital musical performance. Waisvisz made clear for me that developing an intimate musical relationship between a human and a DMI (or a digital machine) was possible, something that I had newly witnessed firsthand in Waisvisz. Additionally, I became aware that in order to properly analyze DMI performance an interdisciplinary approach was necessary. There is much to consider in this comparatively nascent performance practice and it is incumbent to analyze not only the musicological aspects of this practice but also the data capture, mapping strategies, physical gestures, and the cultural aspects belonging to DMI performance.

The gestural vocabulary a DMI designer establishes is, for the audience, the most important aspect of performance. As compared to the data capture and mapping strategies employed, the gestures with a DMI represent the observable aspect of performance and connect the audience to the performer's creative intent. Physical gestures are an embodiment of not only the computational and design elements of a DMI but also the musical outcomes that culminate in performance. The final element of DMI performance discussed here, alongside the data capture and mapping strategies discussed in the previous chapters, provide an analytical framework for dissecting the observable constituents of performance. Through this multi-tiered analytical framework, DMI performance moves further within an audience's action-oriented ontology. Through knowledge of the multiple aspects existing in DMI culture we gain an appreciation of the physical, digital, and philosophical dimensions of this phenomenologically rich musical practice.

Studying Musical Gesture

The study of musical gesture is not a recent development in musicology, however it has evolved with the technology capable of recording physical movement with great precision. New digital technology has equipped researchers with the ability to capture high-resolution motion tracking data offering a detailed and accurate model of an instrumentalist's physical movements during performance. Interestingly, many of these technologies are the same being utilized in DMI performance. Using the same or similar methods to capture physical gestures as data, such as the Vicon system, researchers can analyze the intricacies of embodied musical expression.

By exploring the functions of musical gestures with a DMI, or any instrument for that matter, we can demystify the obscure or confusing elements that exist when observing a digital musical performance. In the same fashion as the previous chapters, setting forth a typology of the gestures present in DMI performance elucidates physical relationships between performers and sound producing systems. Gestural interaction is the most observable attribute of DMI performance and can serve as a lens into the more complicated behaviors of the functionality of the instrument. Musical gestures with a DMI, in conjunction with physical computing, are the visible link between audiences and the digital processes used for sound production.

It is helpful to explain DMI musical gestures using a framework developed for acoustic performing practices while also bearing in mind how the sound producing mechanisms differ. Although this may seem peculiar due to the deviations that exist compared to acoustic music performance, the modality of embodied musical meaning is present in both performing practices. Moreover, much of the music performed by DMI instrumentalists is rooted in Western tonality, formal structure, and meter. Similarly in avant-garde compositional approaches, composers have explored many of the serial, eclectic, and electronic textural or aesthetic qualities extensively before and alongside the advent of digital and electronic technologies utilized for DMI performance. DMI performers working within experimental aesthetics can be viewed as belonging to a larger musical tradition pioneered by classical composers starting in the early twentieth century.

Composers began diverging from conventional performing practices by developing new modes of organizing musical material and implementing extended techniques for acoustic instruments. Successively, this gave way to new methods of creating sound using electricity and by manipulating magnetic tape. Avant-garde music making using new technology by way of bricolage began to emerge. In the digital idiom, the technology available has allowed music making systems to become small enough to be hand held and capable enough to carry out multiple tasks simultaneously in real-time. Recognizing DMI performance as an extension of an established mode of musical performance beginning in acoustic practices explains the suitability of an acoustic typology of gesture for analysis. The following bibliographic analysis will consider solo performance only, group performance gestures have been included in other analyses of musical gesture (Davidson 2010, Dahl et al. 2010), however the breadth of a multi-instrumentalist analysis is beyond the scope of this thesis. To the same end, the embodiment of a musical gesture is that which encodes meaning and artistic expression for an audience despite the number of performers carrying them out simultaneously.

Musical Gesture: Encoding Meaning in Performance

There is much to consider when dissecting performance gestures. Musical gestures possess various qualities that shape the experiential dimensions of a live performance. A musical gesture performed by a solo instrumentalist contains meaning established by the expressive intent of the performer and also through the predetermined formal aspects of the composition. Even when improvisation is present in performance, there still remain steadfast musical elements in performing practices that formulate a gestalt. In the jazz idiom, arguably the performance practice most renowned for improvisation, performers become familiar with numerous conventional intros, outros, breaks, and arrangements standardized by the canonic recordings of the genre. Analogously, solo DMI performers engaging in improvisation have, to a certain extent, musical material and structures predetermined and stored within their instrument as in the case with Waisvisz. Part of his approach to performance utilized short pre-composed musical fragments that were manipulated to create larger musical forms through improvisation. Whether improvised entirely, partially, or read from a score, musical gestures are replete with significance for audiences.

Alexander Refsum Jensenius et al. suggest, in their chapter titled "Musical Gesture: Concepts and Methods in Research" in Rolf Godøy and Marc Leman's text *Musical Gestures: Sound, Movement, and Meaning,* that "until now, there has been no single unequivocal definition of gesture, although most authors seen to agree that gestures involve both body movement and meaning" (Jensenius et al. 2010, 30). The authors imply that their method of delineating musical gestures provides a thorough strategy for analysis. While I do agree that the collection of research in Godey and Leman's text is among the most comprehensive and current resources for musical gesture analysis, the attributes distinct of digital music performing practices are those that require additional contemplation within this scope.

Understanding DMI functionality as the movement of data, as opposed to the physical excitation of organic material, is essential when considering the unique attributes of this performing practice. If we are to understand the encoding of meaning within a musical gesture in part as a relationship between the performer and instrument, DMI performance represents a deviant performing practice. Through the processes of design and configuration the DMI performer develops an extensive relationship with the mechanics and fundamental responses of their instrument. This relationship is also present in acoustic performance however the link between intentional gesture and sonorous outcome is for the most part observable. In contrast, this link for DMI performance can be, entirely or partially, concealed. Analyzing digital musical instrumental gestures hinges on the observable dimensions of live performance and the interpretation by the audience. Strengthening an audience's collective action-oriented ontology must be situated on the familiarity of acoustic performance while recognizing the distinct criteria of DMIs.

A musical gesture is comprised of several elements that provide metaphorical, artistic, and functional communication for the formulation and reception of musical meaning.

> Claude Cadoz, in developing a theory that could capture the notion of physical determinants of gesture space for musical instruments, defined the term instrumental gesture (Cadoz 1988; Cadoz and Wanderley 2000). For him, instrumental gestures are gestures which satisfy three requirements: they contain information conveyed to the audience (semiotic), they contain actions of the performer on the physical system (ergotic), and they encompass the perception of the physical environment

> or context by both the performer and the audience (epistemic) (Essl and O'Modhrain 2006, 285).

The complexity of Cadoz's notion of what constitutes an instrumental gesture is heightened when we consider data capture and mapping strategies in DMIs. The semiotic, ergotic, and epistemic features of gestures with DMIs vary greatly from instrument to instrument. The frameworks explained below have been extracted from typologies developed mainly for the analysis of acoustic musical gestures in Western idioms. The following structure of this aggregate typology will be expanded to account for the characteristics distinct of DMIs. A single musical gesture embodies multiple theoretical and practical elements and is my aim to clarify instrumental gestures with alternate gestural controllers for audiences to foster an appreciation for digital musical performance.

Gesture as Meaningful Function: Control

First, this top tier explains musical gestures by their overarching intentionality or meaningful function. In other words, this tier illuminates how a musical gesture can simultaneously possess multiple characteristics for conveying meaning. For example, the gesture of a guitarist raising their hand in preparation to strum the strings while communicating a musical cue for the band has both communicative and instrument control functions. Through the work of Liwei Zhao and David McNeill, Jensenius et al. propose, "it is possible to define a general framework that considers gestures from the viewpoints of communication, control, and metaphor" (Jensenius et al. 2010, 14). This framework exemplifies the broad aspects of instrumental gestures for music creation and communicative acts for both fellow performers and the audience. Francis Quek et al. identify the prominent difference between types of gestures during speech as either “manipulative” or “semaphoric” (Quek et al. 2002, 172). Miranda and Wanderley, using Quek’s differentiation, bring this two-sided distinction within the context of musical performance as either empty-handed or manipulation gestures, “based upon whether or not they involve contact with a device. This approach yields two groups:

> a. Gestures for which no physical contact with a device or instrument is involved. These can be referred to as empty-handed, free, semiotic, or naked gestures.
>
> b. Gestures where some kind of physical contact with a device or instrument takes place. These can be referred to as manipulative, ergotic, haptic, or instrumental gestures” (Miranda and Wanderley 2006, 4-5).

It is important to note that control, communicative, and metaphoric gestures can be executed as empty-handed or manipulative gestures.

The expectations audiences have accrued, through the long history of musical performance, pertaining to the musical outcomes of physical interaction are well established but have been challenged by digital idioms. Digital musical performance viewed through the lens of an aggregate performance gesture typology, and the ancillary taxonomies presented of gesture capture and data mapping, will explicate DMI performance as an accessible mode of musical entertainment. The breadth of the research carried out on the subject of gesture analysis is far too extensive for the scope of this thesis, however the typologies extrapolated represent the most salient aspects of digital musical performance that aid audiences in understanding the intricacies of performing with DMIs.

At the most fundamental level, observed instrumental control gestures relate to a performer's interactions with an instrument for the production of sound. Control gestures are the foundation of conventional pedagogy focusing on correct procedures for playing a musical instrument. When first learning to play an acoustic instrument we are instructed as to how to support the instrument properly, position our bodies in an efficient and comfortable position in relation to the instrument, and physically interact with the material aspects of the instrument that produce sound.

Developing instrumental control gestures is the predominant focus of musical pedagogy at the onset of learning to play an instrument. The term *control gesture* is nebulous due to how it's usage in the discourse somewhat denotes they require physical contact with a device or instrument. Initially, this appears to be cordoned off to manipulative gestures, however empty-handed gestures can contribute to the production of musical sound in both acoustic and digital practices. In the digital realm, control gestures are veiled under the data capture and mapping strategies configured by the DMI designer and, depending on how explicitly these gestures can be observed, may contribute to the obfuscation between physical interaction and produced sound.

Gesture as Meaningful Function: Communication

The next function of gesture as a vehicle for relaying meaning during performance, identified by Jensenius et al., is that of communication. Much of the literature illuminates the “linguistic communicative aspects of gestures” and “the intended or perceived meaning of the movement or expression” (Jensenius et al. 2010, 15). Despite the linguistic focus of Jensenius’ groundwork, using the research of McNeill (McNeill 2000), the implications for musical applications are notable. Communicative gestures are those that do not directly affect the production or manipulation of sound and occur either between musicians or between a musician and the audience. Communicative gestures exchanged between performers act as a means to ensure the proper execution of predetermined musical events that are organized within the musical score. Making eye contact, facial expressions, breathing and preemptive bodily movements are some of the ways that musicians can ensure simultaneous entries, matched dynamics, and synchronous endings. The players within a symphonic orchestra can rely on the conductor for these musical queues but in smaller consorts the performers themselves must find ways of communicating these necessary features of a musical performance.

Due to the importance of audience expectations in observing musical gestures within an imagined body schema, the embodiment of the communicative aspects in DMI performance take on a greater importance when engaging the audience in musical communication. Due to somewhat differing performance expectations, the DMI performer must find novel ways of entertaining and communicating with audiences. In the EDM (Electronic Dance Music) idiom, additional entertainment elements are regularly present especially in dance clubs and music festivals. DJs and dance music performers often employ complex lighting elements and more commonly video displays. In dance music concert settings, the VJ (Video Jockey) has become a common performer further engaging the audience by providing a multi-sensory music based experience. Projectionists and VJs technical systems are now more commonly networked with the digital musical systems creating synced visual output that reacts to the performed music. In multi-performer scenarios, DMI practitioners often utilize an internal or external hardware clock capable of synchronizing multiple digital systems via slaving (a process that allows scheduling communication between devices), negating the need for inter-ensemble communicative gestures for cueing musical events. Synchronized visualizations accompanying performed digital music can also be found in smaller, avant-garde, and otherwise "underground" or academic settings. DMI performers have engaged audiences in subversive ways possible only through digital means.

During a solo performance by Michel Waisvisz, uploaded to YouTube in 2008 by STEIM from their VHS archive, he engages the crowd and proceeds to incorporate the acoustical result of this interaction into his performance. During the moments before Waisvisz begins performing with *The Hands* he bows and the audience customarily greets his presence on stage with applause. He records the applause and begins to playback and manipulate the captured sound. He seemingly desires a louder sample to utilize in his performance and stops his instrument from producing sound and bows once more. This gesture communicates his wish for more applause and subsequently motions with one of his hands encouraging the audience to applaud louder. Through this communicative act with the audience he begins his performance using the sound material captured via a microphone in his instrument. The gestures conducted by Waisvisz, as a means to gain source material for his performance is an example of how communicative gestures can be utilized not only to communicate with an audience but also to use the audience themselves as an integral component of the larger musical form. Had his gestures not have played part in the musical outcome of the performed music it would be hard to make a case that they should be considered essential to the musical output. However, the sound-producing or sound-supporting nature of communicative gestures situates them as a necessary phenomenon of musical performance.

This example of Waisvisz's wit in performance exemplifies the flexibility of DMI construction and how it can contribute to a recontextualization of performer-audience behavior and communication. While communicative gestures are ubiquitous in all musical performance practices, the adaptability of DMI construction has opened additional avenues for communication using musical gestures for both performers and audiences.

Gesture as Meaningful Function: Metaphor

Lastly, the aforementioned authors outline the metaphorical aspects of musical gestures through the lens of scholarly research attempting to define the emotive, cultural, and psychoacoustic responses linked to physical movements observed during performance. Metaphorical gestures have been described by Eric Métois as able to “communicate musical intentions at a higher level than an audio waveform” (Métois 1997, 16). The metaphorical dimension of musical gestures is ill defined and, to a degree, ineffable as it frames physical expressiveness as an agent that excites emotion; a phenomenon predicated upon the perception of listeners and their action-oriented ontology. Furthermore, the definitions Jensenius et al. state “that there is a flow of communication between the performer and the perceiver, and movement becomes a gesture only if it is understood as such by the perceiver” (Jensenius et al. 2010, 18). If the defining characteristic of metaphorical gestures is that they must be perceived by a listener, the disparity of recognizable gestures between the DMI performer and layperson is great. Although it may remain that much of the extra-musical communication may be lost on an inexperienced perceiver of digital musical performance, it is untenable that the uninitiated could experience a metaphorically devoid musical performance. The metaphorical elements in communicating musical meaning through a self-configured digital system can go largely unobserved for those unfamiliar with the inner workings of a DMI, however the musical gestures are nonetheless encoded with expressive potential. The principle psychoacoustic conundrum facing DMI performance resides in the audience; until a familiarization of physical computing techniques is common, the meaningful metaphorical functions of DMI gestures will greatly vary between audience members.

Musical Gesture: Making Music Through Instrumental Control

In the discourse defining musical gesture as the foundation of musical sound are many typologies that arrive to very similar conclusions. In contrast to framing musical gesture as a modality for expressing artistic intent and features that otherwise lie “behind” the music, the following scheme expounds gesture as the exciting force for musical creation. In this scope gestures are categorized by function of creating sound and accounts for the physical interactions with instruments as opposed to the resultant meaning of performed gesture. Using multiple typologies in the field of musical gesture analysis, I have classified these types of gestures into three categories symbolizing the music making functions that directly excite sound, those necessary to support the instrument, and finally those that are necessarily present but do not contribute to actual sound production. Those necessary but do not directly contribute to the production of sound often have a communicative aspect however a distinction from the meaningful communication classification above is made to account for the underlying intention of why a communicative, referred to as ancillary below and as “free or empty-handed” by Cadoz and Wanderley, is executed (Cadoz and Wanderley 2000, 78). The communicative function of gestures may impart meaning to the audience pertaining to the larger musical forms or of the feeling of a composition in a broad sense, as explained through the example of Waisvisz’s interaction with and manipulation of the audience. Another instance of this could be the consistent sombre body language of a performer aiding in communicating the overall seriousness of a threnody or ballad.

Communicative gestures under this second scope represent those that directly influence the smaller aspects of musical performance that make up a larger musical structure. Under this umbrella, gestures that control substantial musical elements should be defined as *macro-gestures.* They are defined as “extended gestures” by Tor Halmrast et al., but are a logical extension of their critique of “the micro-gestures that create minute inflections of pitch, dynamics, and other features in the course of a single tone” (Halmrast et al. 2010, 183) as explained later in this chapter.

Noisemaking musical gestures first contain a sound-producing or sound-modifying component that directly influences the sound produced by an instrument. In acoustic instruments this is achieved by exciting the material properties of the instrument. Secondly, noisemaking gestures most often also contain support and phrasing characteristics, called *accompanist gestures* (Miranda and Wanderley 2006, 9) or *sound-facilitating gestures* (Dahl et al. 2010, 36), that may not contribute directly to the produced sound. Some examples of sound-facilitating gestures are breathing motions that help performers visualize musical phrases with the expressivity desired or larger motions of the arms that help a performer's hand move across the playing surface of an instrument in a smooth and efficient manner. Lastly, noisemaking gestures may also contain theatrical or communicative features, again distinct from meaningful communicative gestures, and have also been defined as "sound-accompanying" (Dahl et al. 2010, 36). *Ancillary gestures* (Miranda and Wanderley 2006, 10) embody the theatrical and communicative aspects of performing music and communicating extra-musical meaning of musical passages to an audience.

The contemporary definitions of the functions of musical gesture within the discourse overlap and sometimes, as in the case above, a single term is used to define differing functions of gestures. The following ordering of musical gesture by function attempts to clarify discrepancies between multiple typologies and create an accessible analytical framework for listeners of all levels of familiarity with digital music performance.

Gesture as Musical Function: Sound-Producing and Sound-Modifying

Sound-producing and sound-modifying gestures are instrumental interactions that either excite or modify the sound-producing mechanism(s) of an instrument. In acoustic performing practices these gestures excite the physical properties of the instrument. Plucking or bowing strings, blowing into mouthpieces, depressing keyboards, or striking membraphones and idiophones summarize the basic actions for exciting sound from acoustic instruments. Sound-modifying gestures affect characteristics or aesthetics of the sounds capable of an instrument. Pitch, articulation, volume, and the timbre of the musical notes outline the aspects of produced sound by way of sound-modifying gestures. It is significant to bear in mind that:

> gestures might be nested, in the sense that several actions that follow each other may be perceived as one coherent gesture. For example, playing a scale run on a piano may be seen as a series of separate actions if the focus is on the finger movements, but can also be perceived as one coherent gesture if the focus is on the movement of the hand or upper body (Jensenius et el. 2010, 22).

In digital musical performance, the sound-producing and sound-modifying functionality of a DMI is such that a single gesture with the instrument can trigger multiple actions within the software environment. In other words, an isolated DMI gesture can have recursive or sequential properties that negate the need for continuous gesture with the instrument.

Despite this ostensible ease of “playing” a DMI, the sound-producing ability of these types of instruments is adaptable, being considered and configured before the performance takes place. Moreover, the complexity of the movements required and the amount of sustained interaction required vary from performer to performer and from composition to composition. It could transpire that one could sequence a number of musical processes in a DMI that create a lengthy musical piece activated by a single keystroke, however the gestural analysis of this performance would be quite simple. The complexities in human-computer interaction possible within this performing practice are pushing the boundaries of our relationship with computers as tool for conveying meaningful artistic expression.

Gesture as Musical Function: Sound-Facilitating

Sound-facilitating gestures are those necessary for supporting sound-producing gestures. While the discourse can be unclear as to what constitutes a sound-facilitating gesture; in the interest of simplicity, sound-producing gestures should fall under the above category and following Dahl et al. deem sound-facilitating gestures as those that do not produce sound. These types of gestures occur for the support of both a performer's body and their instrument during a musical performance, but "may be hard to isolate as they are overlapping with, and bridging between, the sound-producing and communicative gestures" (Dahl et al., 2010, 53).

In digital musical performance sound-facilitating gestures take on a different significance. If we are to understand this type of gesture as movements supporting those gestures responsible for directly creating music then supporting, setting up, or cueing digital musical events can be vague. Firstly, these gestures in DMI performance could very well be indistinguishable from other types of instrumental control gestures. This occurs to a large degree when a laptop computer is used as a central control device. Using a mouse and/or keyboard in performance may remove the expressive capability of other sensors and further render music making interactions trite. Sound-facilitating gestures with DMIs can be as rich and interesting as in acoustic performance, however this reality is seen only with DMIs that require the capture of bodily movements as opposed to those that chiefly use common HID (Human Interface Device) data.

Gesture as Musical Function: Communication and Theatrics

The final category of musical function gestures encompasses those that don't directly influence the sound produced by the instrument but help to convey artistic intent during performance. They can be defined as the communicative or theatrical gestures observed by audiences and assist a performer in arousing various reactions from an audience or by communicating explicitly the emotive response desired. Ancillary gestures can also aid the musician in interpreting musical phrasing and defining compositional divisions and distinctions. The nature and behavior of musicians' ancillary gestures of choice vary greatly and are determined by the performing practice culture specific to both genre and instrument.

In DMI culture these types of gestures also vary greatly if we consider the breadth of digital music genres that exist. The performing conventions appropriate for a dance club differ greatly to those appropriate for a concert hall. The performance environment is in and of itself the principle agent in dictating the behavior of performers. In comparison to the *communication* category in the meaningful function framework, much of the same carries forward into this category pertaining to musical function. However, the foremost distinction is to what musical element a gesture or set of gestures and encoded meaning is intended. If in a broad sense, the communicative gestures possess a perceivable element contributing to the transmission of the artistic intent of a larger musical form then they should be analyzed within the context of meaningful function. Contrarily, in this framework the function of communicative gestures in focus pertain to relaying musical intent within smaller musical events. In other words, the gestures related to this level of performer-audience communication are perceived within performer movements intended for music creation as opposed to the higher psychoacoustical auspice of a performer's mien.

Musical Gesture: Defining Interaction

Instrumental gestures possess qualities that can be perceived by audiences that define the type of physical effort put forth as a method of creating sound. The final aspect of this aggregate typology clarifies how a performer carries out a particular *meaningfully* or *musically functional* gesture as defined above. Once we can identify a performer's movements as meaningful or functional gestures, we can further define how those interactions are performed.

Tor Halmrast et al. define this level of interaction as *micro-gestures* and they posit that these types of gestures are responsible for the timbreal shifts in the production of tones with an instrument (Halmrast et al. 2010, 183). While it is true that micro-gestures can be responsible for the variations of timbre during performance, all instrumental gestures can also be perceived as occurring through one of the following categories of interaction. This attribute is explained in detail by Rolf Inge Godøy characterizing sound-producing and sound-accompanying gestures but is never explicitly labeled *micro-gestures* (Godøy 2010, 111). Godøy states that musical gestures can be observed as *iterative, impulsive,* or *sustained.*

Iterative gestures are those that materialize as a "rapid repetition of small movements such as to fuse...into a single gesture." Godøy describes *impulsive* gestures as those happening through "discontinuous effort such as in hitting, kicking, rapid stroking, or bowing" and *sustained* gestures as those that happen through "continuous effort such as in continuous bowing or blowing" (Godøy 2010, 111). It is important in this concluding framework through with to perceive musical gesture is that all gestures possess a micro-gestural element whether performed on an acoustic instrument or DMI. Furthermore, this analysis can be applied to describe gestures despite their function, meaningful or musical, to further bring DMI performance with an audience's embodied imagination and to some extent their technical schema.

Micro-gestures, or *instrumental interaction*, account for the closest interactions to the sound-producing mechanisms of an instrument or gestural controller. For example, a guitarist playing a scale up the neck of the instrument could be perceived as an iterative gesture. While comprised of a series of small events, this musical gesture could be perceived as a single musical event, idea, or expression. An example of an impulsive gesture, or those requiring "discontinuous effort", could be a percussionist striking a triangle once. And complementary to impulsive gestures, *sustained gestures,* or those requiring "continuous effort" of the performer, are those such as the continuous bowing of a string instrument to sustain a note(s). Contemplating micro-gestures with acoustic instruments offers a familiar viewpoint valuable for conceptualizing how this attribute of musical gestures materializes in digital practices.

Instrumental Interaction: Micro-gestures with DMIs

Similarly to micro-gestures with acoustic instruments, this level of instrumental interaction lies closest to the sound producing functionality of a DMI. Because the DMI designer configures these interactions, the micro-gestures possible with the instrument varies greatly. Some configurations of alternate gestural controllers may mimic the gesture vocabulary of acoustic instruments, such as striking a playing surface. However, others, as in the case of Waisvisz's ultrasound sensor in *The Hands*, offer deviant methods of exciting musical sound. Micro-gestures typify the point at which the DMI designer assigns the mapping of a captured gesture within the instrument to a sound producing process.

The typologies delineated in this chapter offer a top-down approach, from the philosophical and metaphorical dimensions of musical gesture down through the practical and physiological approaches possible in producing musical output.

The tiered model outlined will aid audiences in observing, understanding, and in turn appreciating digital musical performance despite the disparity that may exist in their technical schema, or actual skills, in this idiom.

Problems for Audiences of Digital Musical Performances: A Summary

Through this proposed aggregate typology of musical gesture DMI performance can, to a greater extent, reside in our action-oriented ontology. In other words, the broad categories in the top level allow for a simple, but valuable, recognition of musically meaningful intent within a gesture. Secondly, one can witness through the lens of the middle tier what gestures make and modify, support, and communicate this intent. However in this final tier, the *micro-gestures* with instruments that use deviant methods of interaction are harder to correlate to musical output. At this level of detail, the intricacies of sound producing and/or modifying mechanisms from the capture of gestural data through their mapping destinations are invisible. The audience, without deliberate explanation or visual aid provided by the performer, cannot observe a clear pathway from gesture to sound. As “without an accurate understanding of the interaction, many spectators found it difficult to assess attributes of the performance” (Marquex-Borbon 2011, 375). Furthermore, in A. Cavan Fyans article, “Examining the spectator experience”, “several participants voluntarily highlighted the fact that they enjoyed the performances more” when the performer “explained the instrument first” (Fyans et al. 2010, 454).

Musical performances with alternate gestural controllers will to an extent remain confusing for audiences. Leman's notion of technical schema and embodied imagination still remain the prerequisites for one's action-oriented ontology but might never be complete for layperson and practitioner audiences alike. The need for employing multiple typologies of musical gesture in alternate gestural controller performance is apparent when we consider the phenomenology of performing with self-configured digital systems. Because the gestural vocabulary can be appropriated from multiple and/or disparate sources, it is often difficult for audiences to equate the performer's physical efforts to the attributes of the resultant sound. When we move a single or group of gestures through this typology, we shed light onto the artistic intent and in turn the musical meaning of a digital musical instrumentalist performing with an alternate gestural controller. In doing so, some of the convoluted aspects in this music performance culture will become clearer for both the initiated and newcomers.

Michel Waisvisz: Virtuosity with an Alternate Gestural Controller

Digital technology has provided additional methods of organizing and playing musical material for many musicians and, for the time being, remains unique in its adaptability. Through Michel Waisvisz's development and mastery of *The Hands* we can easily see the interactive potential in DMI practice. It is imperative to remember that the amount of support that Waisvisz found during the development of his instrument was immense. It is also important to bear in mind that *The Hands* was not an amateur attempt of developing a DMI. The support that Waisvisz was able to make use of is not an accurate representation of this musical culture in general. Most musicians working with DMIs lack the amount of support that Waisvisz found in his artistic community and in the institution that he was associated with and eventually directed. Waisvisz's instrument exemplifies the importance of community comprised of diversely skilled individuals to conceive, design, develop, and utilize a mature digital system in this musical practice.

The types of gestures in Waisvisz's vocabulary were diverse. From swift twitches to slow focused movements, each gesture performed with *The Hands* can be observed as directly influencing the sound produced by the instrument. His instrumental gestures are perceived as deliberate and calculated and elucidate the relationship he had developed with his own instrument. The hollow areas in each of the interfaces fit tightly over his hands as to not allow any unwanted movement when handling the instrument. The three main observable macro-gestures easily observed is his performances were:

a. the depressing of momentary switches using his fingers

b. the "bowing" motion used to utilize the ultrasound sensor that measured the distance between the interfaces on each hand

c. the turning of his hands activating the mercury (or tilt) switches present on each interface

The gesture capture strategy implemented in *The Hands* is an example of direct acquisition. The sensors need to be directly manipulated by the performer in order to produce the data for the sound producing system. Waisvisz's thumbs were harder to observe as they were hidden behind the interface when held in the playing position. His thumbs depressed momentary switches, along with "a pressure sensor and a potmeter", located on the side of the instrument facing him that were used to reassign the functionality of the switches played by the rest his fingers, the tilt switches, and ultrasound sensor in real-time (Bongers 1998).

The mapping strategy used for the momentary buttons in view of the audience is observed as a one-to-one dynamic mapping. The momentary buttons "provide pitch control (MIDI key-on, key-off)" data (Waisvisz 1985). During his performances he also used lively arm and shoulder sound-facilitating gestures to aid in exciting instrumental data. The iterative micro-gestures performed by Waisvisz's fingers are much more difficult to correlate to specific sonorous outcomes as the mappings assigned to those switches are dynamic and can initiate or manipulate the sound at the discretion of Waisvisz. However, those iterative gestures perceived as a larger gesture with musical function allow the observer to more easily understand the connection between the sound-producing and sound-modifying gestures and their affect on the sound.

Perceiving Waisvisz's depressing combinations of the momentary switches on his instrument as a macro-gesture with both meaningful and musical functions moves his performing practice further within the action-oriented ontology of the viewer. Through offering an explanation of how the thumb switches changed the functionality of those switches in the audience's view, the musical gestures he executed become clearer. The embodiment of instrumental gestures is more easily imagined as sound producing movements and the inner workings of the DMI become less concealed. The obscurity of a self-developed DMI makes it difficult for audience members to engage with performers and their specific approach in musical performance. Ideally, performances in this musical idiom are preceded by explanations by the performer although, in my experience, this is seldom offered.

The bowing gesture ubiquitous in Waisvisz's performances is also discernably a one-to-one dynamic mapping. In contrast to the iterative and impulsive gestures executed with the momentary switches on *The Hands*, his bowing gesture perceived as a micro-gesture would best be described as sustained. Making the observation of this gesture's effect on the produced sound uncomplicated and helps engage the audience. The gestures of turning his hands to manipulate the tilt switches were impulsive due to the physical characteristics of the sensor and how it is best excited. Alike his sustained gestures, these gestures are also easy to correlate to their musical function, as the data produced required a distinct and noticeable physical interaction. His communicative gestures occurred throughout his performances, nested within the gestures performed with his hands and additionally through his facial expressions. Waisvisz also played with audience expectations and performing conventions as explained earlier as occurring through communicative acts.

Waisvisz's gestures with his instrument seem to control musical material at the note-level and have processing functions rather than score-level control. The larger musical structure is determined and arranged through the material performed rather than making use of preprogrammed or predetermined computational processes used to organize the overarching musical form. It is extremely difficult to assure the exact function of a particular gesture without the insight of the designer and/or performer regarding the mechanics and the idiosyncrasies of their instrument. The general methods of gesture capture and data mapping can be observed and postulated with some certainty. However, connecting isolable gestures to their precise digital musical functions remains speculative.

What is most captivating for audiences of Waisvisz's performances is that his instrument was designed in a way, most probably deliberately, that required him to move in ways reminiscent of acoustic instruments. This feature of his approach to performance, although his aesthetics may lie beyond popular tastes, made his performances accessible as an embodiment of digitally produced sound though novel means. However, the traits of his gestures were supported by conventional instrumental interactions that stemmed from multiple acoustic performance practices. His vigorous gestures created intense textures while quieter and gentler moments in a composition were performed through slow and pensive gestures. This connection between acoustical principles of conventional instruments coupled with new and interesting ways of controlling sound using digital technology brought about an inspired and engaging musical experience for audiences.

Waisvisz's instrument was able to control multiple parameters simultaneously which further contributed to the complexity of his gesture vocabulary and the interest this created for spectators. By the end of his career his mastery over his DMI was highly developed and his compositions were refined. He is a revered figure in avant-garde digital music performance culture and his accomplishments, as a designer, composer, performer, and artistic director has set a precedent for the control of live music performance through alternate gestural controllers.

The action-oriented ontology of audiences of Waisvisz's performances, and DMI performances in general, would undoubtedly not be as developed as those familiar with the performance practice. Regardless, in opposition to Leman's exposition of what constitutes an action-oriented ontology for musicians, an action-oriented ontology exists for those with minimal technical schema related to making music; using acoustic or digital instruments. All members of an audience are cognizant of embodied musical sound and possess the wherewithal to relate interactions with instruments as sound producing. While DMI performances might be confusing to a general audience, the aggregate typology offered in this thesis will aid those interested in expanding their action-oriented ontology for digital musical performance and for looking deeper within DMIs such as *The Hands*.

Chapter Four

Conclusion: Digital Music Bricolage and Musical Thought

There are numerous resources that provide surveys of self-fabricated musical interfaces (Miranda and Wanderley 2004) and approaches for developing one's own interface (Igoe 2007; Banzi 2009). Also, there exist many resources on various music software and their capabilities (Winkler 1998; Blum 2007). Although indispensable for the electronic musician, these resources mainly serve to illustrate the capabilities of specific hardware and software but fall short in providing DMI specific scenarios. There are also many resources for the analysis of musical gestures, although much of the research focuses solely on acoustic performance practices.

Digital musical performance with alternate gestural controllers has animated a shift in musical thought and in conceptualizing the processes vital to realizing music compositions. The DMI designer as a bricoleur must conceptualize their system as a network of interacting components working collaboratively toward the same end result. This notion of devising complex systems by using data to generate sound has been identified by Eduardo R. Miranda as the "parametrical approach" to music creation.

> The parametrical approach to composition has led composers to think in terms of parametrical boundaries and groupings that probably would not have been conceived otherwise (Miranda 2001, 12).

The digital music bricoleur must consider characteristics of produced sound in ways differing from other music practices. Also, the digital music bricoleur must decide how these parameters of musical sound will be controlled efficiently and expressively. The parametrical approach as viewed through the lens of digital music bricolage summarizes the deviant methods in digital performance as compared to conventional music performance and composition.

The data generated by a digital system can be understood as syntactical. This means that the digital information can move within the digital music making system free of meaning until it is mapped to a musical parameter. Alternate gestural controllers generate data through physical interactions by the performer that are captured through the use of sensors or by generative processes within the system. The data generated by an alternate gestural controller, both from physical interaction from the performer and generative processes, does not have a necessary acoustic component. Therefore, the movement of data within a system can be utilized to affect any parameter imaginable of the generated sound. To which musical parameter the data is mapped is left to the discretion of the DMI designer and the sound producing elements within the system.

Digital music bricolage has expanded the definitions of music composition and performance. Composition in this musical practice cannot be sufficiently understood as the final product of organizing sonic material for sound producing agents. But rather, digital music composers must also consider both the computational processes and the gestural interactions that will organize the compositional structures and affect the aesthetic outcome. Wasivisz himself considered much of his activities as related to the compositional process, including the designing of a DMI (Krefeld and Waisvisz 1990, 28). A digital instrument itself can arrange and reorganize the structure of a composition upon each performance. The adaptability of a DMI differs from both the static structures of both acoustic instruments and conventional notation.

> In interactive music systems the performer can influence, affect and alter the underlying compositional structures, the instrument can take on performer-like qualities, and the evolution of the instrument itself may form the basis of a composition. In all cases the composition itself is realised through the process of interaction between performer and instrument, or machine and machine (Drummond 2009, 125).

Digital music systems have blurred the boundaries of what constitutes both a music composition and musical performance. DMIs offer new methods of organizing and realizing musical material in performance. In this musical practice, a composition can be structured through a performer’s gestures with a DMI, or by the DMI itself. The musical outcomes that can occur can be improvisatory, predetermined, or a combination of both.

> An important characteristic of interactive computer music systems is that the goal of the interaction (the performance) is part of the bi-directional communication between the performer and the computer (Wanderley and Orio 2002, 66).

This bi-directional communication between the performer and the machine summarizes the melding of composition and performance in digital music performance. Digital music systems create a mutually interdependent relationship between the formal organization of music compositions and the instrumental gestures, or interactions, compulsory for musical realization.

Although this relationship occurs in all digital musical practices, it is amplified by the practice of digital music bricolage and especially in case of musicians who design their own alternate gestural controllers. Under this light, DMI performers can be understood as a hybrid of composer and performer. Additionally, the performer of the final musical product also possesses intimate knowledge of the interactive and computational elements that converge to produce the musical work. Thus, it is difficult to draw an analogue between digital and acoustic practices to a degree that the analytical frameworks developed in traditional Western music practices would suffice in accurately analyzing digital musical performance.

The notion of the DMI performer as a bricoleur takes on significance when analyzed using an action-oriented ontologically based framework. An audience's experience of DMI performances becomes situated on the functionality of the music making system as well as the movements of the performer. Bricolage, as observed in the context of DMI performance, is a necessary feature of this performance practice and has produced a distinct method of creating and performing music. Through an expanded action-oriented ontology, observers can better dissect the components of a DMI that allow for embodied musical expression. The aggregate typology constructed in the previous chapters helps audiences understand gestures with DMIs as the inciting force for creating complete musical events or affecting parameters of produced sound through Miranda's notion of the *parametrical approach.* Each musical gesture perceived by an observer as precipitating a musical event can be brought further into their action-oriented ontology by using this typology as an investigatory tool.

Alternate Gestural Controllers and the Aggregate Typology

Musical performance using alternate gestural controllers is distinct in that the performer's creative intentions are literally built into the instrument. Each captured gesture must be predetermined as useful and appropriate for communicating embodied creativity. Subsequently, each gesture embodied in the instrument must be mapped to a musical parameter within the system of the DMI. Performers in this musical idiom, especially those who design and perform with alternate gestural controllers, create a collection of musical gestures to be recognized by the functionality of the instrument and subsequently by the audience. Difficulty can arise when analyzing gestures in alternate gestural controller performance through their ability to capture gesture vocabularies from various instrumental practices and for developing novel modes of interactivity. Every DMI will inevitably encompass a unique combination of possible interactions and sound producing capabilities. Despite the distinct nature of these instruments, we can more clearly understand this musical practice when a gesture typology accounting for DMI design is considered.

The computer is a highly capable tool able to assist a performer in achieving their imagined musical aesthetics and methods of physical control. Musicians working with digital technology now have a great number of options for making connections between their bodies and musical output. In addition to adopting modes of interaction already existing in other performing practices, DMIs can utilize extra-gestural connections that are not present in acoustical practices. Bio-signals, motion tracking, face and voice recognition, 3D scanning and printing, projection mapping, and other new tools entering our media landscape offer new modes of interaction with computer processes for music creation. If these digital tools are any indication of what the future might continue to bring, we will see a continued trend of heightened interactivity with digital technology and a fertile ground for computer assisted musical creation.

Performers and Audiences

The phenomenon of DMI construction sheds an interesting light our understanding of musicians and where they lie in relation to their instrument. The instrument itself is not a preexisting structure accompanied by comprehensive pedagogy, standardized techniques, or established historical contexts. By comparison to acoustic instruments, DMIs are more dynamic in their interactive potential and the gestural vocabulary they can encompass. The digital music instrumentalist in this context can be understood not only as a performer but also as possessing ancillary skills necessary in developing their unique instrument.

Digital musical performance in this idiom requires musicians to acquire skill sets not needed in other instrumental practices. It is entirely possible that one might have a DMI built for them by someone else, however the performer must always learn to play the instrument they use outside of their role in its development. The phenomenon of instrument development is a key component in understanding digital music instrumentalists as bricoleurs. This expanded phenomenology of performance is due, in part, to the fact that the interactive potential is prescribed by the performers and designers. The process of self-configuring an interactive tool capable of musical performance reaches further into the complexities of artistic intent and execution.

For audiences, this emergent mode of musical performance will, to an extent, continue to be troublesome to comprehend until the technologies used become familiar. As multi-touch displays, computer vision, high-resolution sensors, and other new digital tools become more prevalent in our immediate media ecology, our understanding of the behaviors and exploitation of this technology will expand. Through an inevitable heightened cognizance of the applications of digital technology it will become possible for future audiences to peer into the inner workings of a DMI with ease.

Through this typology, observers of DMI performances can more accurately look into the intricacies of this practice. Viewing the DMI performer as a bricoleur sheds light onto the multiple tasks they must accomplish before the performance takes place. An understanding of typical designs of DMIs also helps audiences in situating the instrument observed in performance within a larger cultural context. Knowledge of commonly employed hardware and sensors aids in perceiving physical movement as generated data.

Moving an observed musical gesture through this typology also illuminates how the produced data can be mapped to musical parameters. A member of an audience can more precisely perceive the allocation of data moving through the digital system, and its function in creating or manipulating the resultant sound. This experience dissolves the ambiguity that may be present between a performer's movements and the acoustic result. By analyzing the gesture vocabulary utilized in a performance the observer experiences not only the embodiment of artistic expression but also the extra-musical facets communicated through ancillary gestures. Gurevich and Fyans' study of the perception of digital musical interactions "showed that spectators' perception is especially attuned to bodily cues and gestures when they don't have access to an understanding of the performer–system relationship or where the musical context doesn't provide a clear sense of expectation" (Gurevich and Fyans 2011, 173). Interestingly, the process of examining the instrumental gestures with a DMI also further informs the methods employed for gesture capture and the mapping strategies present in the system. This analytical approach can aid audience members in better understanding embodied musical gesture during DMI performance.

Final Thoughts on Performing with Musical Machines

Digital technology has not only become more capable and smaller in the last several years but, the devices that can be easily employed for musical performance have also become more affordable. The ubiquity of mobile devices and the ease of disseminating music making applications through online stores have democratized access to highly developed digital music making tools. As mentioned in the second chapter, the once steeply priced JazzMutant Lemur multi-touch digital music device (approximately $2,500 USD) is now available as an app for $49.99. The highly acclaimed Tenori-On hardware device designed by Toshio Iwai and manufactured by Yamaha can be purchased for approximately $1000 but is now available as an app for $19.99. The list of expensive digital music hardware devices now available on the App Store and Google Play for a small fraction of the price is continuing to grow. It could be argued that an application is no substitute for a hardware device and the gestures possible with devices such as tablet computers are indistinguishable from one another. Notwithstanding, mobile devices "offer a richer gestural repertoire and palette of sensing technologies", that have potential for music making not yet fully realized (Gurevich 2012). What is most salient about digital music consumer products in the tablet computer market is that these once esoteric modes of musical interaction are finding themselves in the hands of a vastly larger user base. Though the exposure possible through the digital dissemination of music making applications, a consolidation and standardization of terminology and an understanding of synthesis and structural approaches in this idiom is imminent.

These new music making tools, now in the hands of many, have and will continue to foster interest in creating music using digital technology. Exactly how and to what ends this technology will be utilized is impossible to predict, but we can be confident that DMI development will occur through acts of bricolage. Artists will incorporate various tools in subversive ways to create larger systems for music making. Digital music bricolage will continue to push the boundaries of how we configure machines to achieve artistic ends. Musical gestures with DMIs posses the ability to recontextualize an audience’s expectation of what necessitates an observable musical gesture. As digital music making tools find themselves more comfortably in the hands of the general public, an expanded action-oriented ontology for digital musical performance will be found.

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Appendices

Appendix A: Digital Hardware

General Aspects of Digital Music Systems

There exists a difficulty in understanding self-fabricated systems for the listener of digital music compositions. The compositional methods of digital music composers are not explicit in recordings and the listener can only guess as to the structure of the digital system. Musicians familiar with synthesis and digital signal processing techniques indeed develop the ability to identify the processes responsible for the generation of the digital sound heard. However, the specific music technologies capable of generating these aesthetics are now widely available and numerous. There are many decisions that must be made by the digital music bricoleur to create the desired musical effect, all of which possess musical consequences.

> The challenge facing the designers of interactive instruments...is to create convincing mapping metaphors, balancing responsiveness, control and repeatability with variability, complexity and the serendipitous (Drummond 2009, 132).

Developing an exhaustive taxonomy of possible manifestations of digital music systems is not only beyond the scope of this thesis, but it is arguably impossible. Nevertheless, there are broader categories that outline some of the considerations that take place in the practice of digital musical system configuration.

1. Digital Exclusivity versus Digital Incorporation

There are an indeterminable number of ways composers can arrange digital components to achieve various ends. Some composers work exclusively with electronic and/or digital technologies and others who incorporate acoustic instruments within a digital system. In both cases the composer must consider the interactive possibilities created by incorporating each digital component into their system. An acoustic instrument included in a digital system is able to interact with the computational processes occurring within the system. The acoustic instrument in a digital system is recontextualized in the sense that aspects of the acoustic performance can be converted into data and used to manipulate digital processes. Both approaches embody bricolage to the extent that the musician builds a larger structure from multiple elements in their environment. The resultant structures built by bricoleurs use these elements (digital, acoustic, or both) in a manner that deviates from their conventional and expected use.

2. Determinacy versus Required Interaction

The use of digital and computer technology for musical outcomes is adaptable due to its ability to either carry out multiple computational processes simultaneously or to trigger events in succession. A DMI can execute sequential instructions that may negate the need for continuous interaction from the performer. This characteristic could come across to an audience to the same degree as a performer pressing play on a CD player, instructing the system to initiate a series of musical functions and then stop automatically. This is an extreme example, but the use of automated processes is ubiquitous in digital music systems. Contrarily, a DMI can be devoid of automated processes requiring continuous or sustained gestures from the performer to produce sound. DMIs such as these are a direct parallel to acoustic instruments; when the mechanical, material, or digital elements cease being excited the instrument falls silent. This contrast is explained by Todd Winkler, in his book *Composing Interactive Music: Techniques and Ideas Using Max*, as “predetermined and improvisational” events (Winkler 1998, 28-29). The DMI designer must decide which audio producing processes within the system are to be automated or require continuous gesture. While gesture mappings that trigger automated events are common and useful, they obfuscate the observable link between embodied musical intent and the resultant sound.

3. Linear versus Nonlinear Systems

Winkler also considers the way in which musical architectures can be organized or structured within a digital system.

> Compositional structures may be considered linear, with sections of music ordered sequentially as in a traditional score, or nonlinear, with sections ordered differently for each performance, determined by performer input or computer processes (Winkler 1998, 31).

Alongside the formal aspects of a composition within a digital system, the control elements of that system can also be organized either linearly or nonlinearly. For example, a hardware interface could be used to organize the formal structure of a composition that in turn generates predetermined sonic events. Conversely, that same interface could be used to generate sound only leaving the architecture of the composition to be improvised or organized in real-time. The digital music bricoleur organizes the elements of their system to reflect the amount and type of physical interactions needed to organize the larger structure of the piece of music alongside the textural and timbreal elements.

Four Main Types of DMIs

There have been a few efforts in developing a comprehensive typology of digital musical instruments yet none as thorough as Eduardo Reck Miranda and Marcelo Wanderley's text *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard.* In this book they offer a typology of DMIs that were prominent at the time of its publication in 2006. Although the above work was written several years ago, the technology and approaches in design discussed are still prominent in DMI performance culture. Their taxonomy spans DMI configurations that are mere modifications of acoustic instruments through exclusively digital musical performance systems. They posit four distinct classes of DMIs: augmented musical instruments, instrument-like gestural controllers, instrument-inspired gestural controllers and alternate gestural controllers. Similarly, in 2007, Dan Overholt had also developed an aggregate typology of DMIs in his dissertation based on the research of several scholars (Overholt

2007, 63-67). Overall, Overholt's typology is almost identical to Wanderley and Miranda's less a few minor details and discrepancies in terminology. Most important is the fact that although these scholars often collaborate on research, these leading experts in the field of digital instrument design are arriving at a consensus regarding the possibilities and capabilities of the instruments used in this performance practice. As digital musicians, and those that study DMIs, arrive at comprehensive definitions and standards for DMI performance practice a unified vernacular will surface. In turn, one could assume that this musical practice will become better situated in the action-oriented ontology of audiences.

Augmented Musical Instruments

The first category of DMIs, identified by Miranda and Wanderley, is *augmented musical instruments*. Augmented musical instruments are pre-existing acoustic instruments whose functionality is extended by incorporating digital components. One of the most common approaches of this category is the modification of wind instruments using sensors on the keypads and/or body of the instrument (e.g. the "Hyper-Flute" (Palacio-Quintin 2003) and "Metasaxophone" (Burtner 2002)). String instruments have also been a popular choice to augment into a DMI. Curtis Bahn's DMI named the *Sbass*, short for sensor bass, is an upright bass boasting extra functionality via multiple pickups, a contact microphone, a touch-pad under the fingerboard, and "several extra buttons." Dan Trueman and Perry Cook have developed a bow to augment violin performance without the need to affix components to the body of the instrument. Trueman and Cook's *Rbow* allows the violinist to generate gestural data with their acoustic instrument using a conventional gesture vocabulary. Within this category of DMI, performers can maintain established performance techniques while producing supplementary data, and in turn digital musical material. Performers using augmented instruments utilize the data produced as a means to extend the preexisting timbre and performance conventions of the original instrument.

Augmented musical instrumental gestures are founded on the preexisting techniques of the acoustic instrument being augmented. Strategies for gesture capture are also commonly organized on the performance practice of the instrument being extended. In most instances, the sensors utilized are often arranged overlying conventional playing positions; the way in which musicians are trained to hold their instrument. This makes short work for acoustic instrumentalists to perform with this type of DMI. However, the authors note that the "maintenance" and "obtrusiveness" of the extra components can prove cumbersome in performance (Miranda and Wanderley 2006, 25). The added weight and position of the sensors, cabling on an instrument or bow, or the altered shape of playing mechanisms are examples that have proved challenging for augmented instrument performers. While the types of gestures typically captured by an augmented instrument are usually those belonging to the performance practice of that instrument, the implementation of sensors that require the performer to move in unconventional ways to excite sensors is also found.

Instrument-Like Controllers

The second category in this typology are *instrument-like controllers* and account for digital instruments that “seek to model an existing acoustic instrument as closely as possible” (Miranda and Wanderley 2006, 25). A commercially successful and widely used example of this type of DMI is Akai’s EWI (Electronic Wind Instrument). The EWI resembles a clarinet having a long and slender shape that is played by holding the instrument vertically and in front of the performer. The mouthpiece of the instrument is blown into like a wind instrument and produces MIDI data to be routed into a sound producing system. Using a combination of air pressure sensors and momentary switches the performer, using the customary fingerings belonging to aerophones, generates MIDI note and velocity data corresponding to fingerings and forcefulness or breath respectively.

The entry level model of the EWI is incapable of producing sound on its own requiring the instrument to be connected to a larger sound producing system like a synthesizer, however the higher level model boasts a built-in sound producing “module.” The data captured by the instrument and its intended function can be anticipated as the gestural data directly corresponds to the behaviors of an acoustic instrument. In addition to the MIDI note data corresponding to the fingerings belonging to wind instruments the velocity of each MIDI note is mapped to the breath sensor. Thus, the more forceful the performer's breath the higher the velocity of the MIDI note and in turn the louder the resultant note might be when sounded by a typical synthesis process.

Instrument-Inspired Controllers

The next, and somewhat nebulous, category is *instrument-inspired controllers*. These controllers can deviate from both the interactive and design conventions of acoustic instruments but require "somewhat familiar gestural vocabularies inherited from the acoustic instruments from which they were inspired" (Miranda and Wanderley 2006, 27). Designers of instrument-inspired controllers develop interactivity through gestures based on preexisting acoustic performance practices.

An example of this type of DMI provided by the authors is Max Matthews' DMI the *sequential drum* (27). The design of this DMI consists of a playable surface responsive to strikes from the performers hands or drumsticks. The sequential drum outputs the coordinates struck on the playing surface as well as the force of each strike. Modeled after a percussion instrument this DMI produces data through gestures belonging to the performance practices developed by percussionists. Although inspired by and played like an idiophone, the data generated from the sequential drum can be freely assigned to sonorous processes.

The above three design categories of DMIs, although progressive in expanding the expressive possibilities for musical performance, all conform to gesture vocabularies developed through acoustic performing practices. These established musical gestures communicate familiar modalities for the audience. The gestures that are found in performance with the above DMIs are rooted in acoustic instrumental performance and thus are more familiar to audiences. Due to the recognizable attributes of acoustic based musical gestures with the aforementioned DMIs, performances with these instruments are well situated within an audience's action-oriented ontology. Musical performances with all types of DMIs outlined above necessarily contain musical modalities that lie within the boundaries of an audience's embodied imagination and technical schema.

Alternate Gestural Controllers

The final category of DMIs in Marcelo and Wanderley's typology is *alternate gestural controllers* and is explained by the authors as those "not directly modeled on or necessarily inspired by existing acoustic instruments" (Miranda and Wanderley 2006, 30). This category summarizes the type of DMI that best exemplifies the problems examined in this thesis. Alternate gestural controllers are divergent in their design and interactivity and best represent the digital performance practice in need of analysis when considering interactions with computers and or digital technology as musical gestures. Furthermore, the functionality of most alternate controllers is made possible using digital components exclusively. The current unfamiliarity of creating music with unconventional digital systems contributes to positioning DMI performance with alternate gestural controllers on the periphery of musicological discourse and entertainment culture.

Within this last category of Wanderley and Miranda's typology they posit three sub-categories of alternate gestural controllers: Touch Controllers, Expanded Range Controllers, and Immersive Controllers. Additionally, within the Immersive Controllers category exists a subset of: Internal Controllers, External Controllers, and Symbolic Controllers.

Touch controllers are DMIs requiring the performer to physically touch a control surface. Before the recent ubiquity of the tablet computer, such as iOS or Android devices, the leading multi-touch display controller intended for musical applications was the *Lemur,* manufactured by the French company JazzMutant. The device featured a variety of customizable user interfaces and offered support for the OSC and MIDI protocols as well as presets for controlling popular digital audio workstations (DAW) such as Ableton Live. At the height of its domination of the multi-touch display for music making market, the Lemur came at a price point of around $2,500 USD making it inaccessible to many digital music makers. In late 2010, the company announced that the Lemur would no longer be manufactured as a standalone device. The emergence of comparatively low-cost multi-touch devices forced JazzMutant out of the market and one can now purchase the Lemur software for iOS for $49.99 USD. This forward thinking but once expensive technology has been democratized in the sense that multi-touch controllers for musical creation are finding their way into the hands of more and more musicians.

Another extremely prolific touch controller made by a small Pennsylvania based company is the Monome. Conceived, developed, and manufactured by Brian Crabtree and Kelli Cain, this device has largely remained unaffected by the burgeoning tablet computer market. Since Monome's debut in 2006, these devices have been extremely sought after. Despite the sizable cost of $500 USD for the most inexpensive model, they have remained difficult to acquire throughout the company's history. Described as "minimalist" in its design, the lowest level Monome model features an 8x8 grid of backlit physical buttons that provide the performer with visual feedback of the computer processes taking place as the instrument functions. The creators of the Monome describe the device as adaptable as the sound producing functionality is made possible not by the device itself but by computer programs made most often in Max/MSP.

Both of these touch controllers have made a mark on digital music culture, most notably by giving musicians access to preassembled devices that could be easily by integrated into onstage performances. The commercial success of such devices not only signifies the need for alternative expressive interfaces for musicians, but the interest of audiences to understand and accept unconventional gestural controllers as belonging to a digital musician's identity.

The immediacy of gesture to sound typically present in touch controllers allows embodied gestures to be comfortably decoded by audiences as meaningful and musically engaging.

Expanded Range Controllers require performer to either touch a physical interface or be present in an interactive environment, but both to a “limited” degree allowing the performer to “escape” the sound producing apparatus/environment (Miranda and Wanderley 2006, 31). The *Buchla Lightning II*, invented by Don Buchla, is one of the examples given of this type of controller. This DMI consists of two wands held by the performer and tracked by an IR receiver placed in front of the performer. The instrument outputs four continuous streams of data, reporting to the x and y axes of each wand, in addition to the states of multiple switches included in the body of the wands. The performer is able to make movements while operating this DMI that do not directly influence the sound produced, or how the authors describe as being able to “escape” the instrument. The example of this type of DMI that I analyze in further detail later in this thesis is *The Hands*, designed by Michel Waisvisz at STEIM (STudio for Electro-Instrumental Music) in Amsterdam, the Netherlands. *The Hands* can be understood as an expanded range controller that is worn on the performer’s hands and is controlled by multiple pushbutton switches depressed by the player’s fingers in addition to motion and proximity sensors. However, the mastery Waisvisz gained over his instrument allowed him to maneuver the instrument, despite the motion sensing components, without effecting the musical processes.

Immersive Controllers are juxtaposed with expanded range controllers by making the distinction that performers using these DMIs are unable to "“escape” the control surface" (Miranda and Wanderley 2006, 31). Through the work of Axel Mulder, (Mulder 2000, 315-335) Marcelo and Wanderley delineate immersive controllers as having three subcategories that "can be grouped according to the visualization of the control surface into the following categories:

> a. *Internal Controllers*: the control surface visualization is the physical shape of the body itself.
>
> b. *External Controllers*: the control surface is visualized as separate from the performer's body. It may even be impossible to visualize it as a physical shape.
>
> c. *Symbolic Controllers*: the control surface is not visible; it requires some sort of formalized gesture set (sign language, conducting) to be operated" (Miranda and Wanderley 2006, 31).

These subcategories of immersive controllers account for those types of DMIs that are extremely unconventional when compared to acoustic instruments. Immersive controllers are designed so that the performer's position and/or bodily movements are constantly being analyzed and relayed by the DMI. The boundaries between the categories of alternate DMI designs are somewhat fluid, as instruments may possess multiple strategies for achieving interactivity or a

DMI may be a combination of interfaces within a singular digital music performing system. For example, a DMI can be an immersive environment that tracks the position of a performer within a defined space while simultaneously requiring input from a touch or expanded range controller. Needless to say, the number of possible configurations is vast. The distinctions made between the types of immersive controllers (internal, external, and symbolic) relate to how the virtual representations of the performer's gestural movements are organized within the software element of a DMI rather than the mechanical or physical computing constituents.

Immersive controllers often take the form of clothing, such as gloves or body suits outfitted with various sensors and/or passive markers that are tracked by a camera or other positioning system. The Lady's Glove, conceived by Laetitia Sonami and built by Bert Bongers, is a movement sensing DMI that underwent several iterations, the final of which boasts a large array of sensors and transducers that create data for musical control. Being a glove the performer wears, this instrument creates a unique relationship between musician and potential musical output. The Lady's Glove was developed as a means to control musical parameters "allow(ing) movement without spatial reference." Designing a musical instrument that removes the necessity of physically holding an object is an interesting approach for musical control. It establishes new ways of imagining the role one's body can be used to create sound. However, researchers in this field might only consider instruments such as *data gloves* partially immersive as they cover and monitor only part of the body.

Another significant approach in creating, usually *totally immersive*, sensing environments for gesture capture is by use of motion tracking. Technology such as the Vicon line of motion capture systems and other such high-end systems for analyzing physical movement offer DMI designers robust environmental and gestural data. The Vicon system utilizes several high speed cameras positioned around the perimeter of the desired interactive area. Each camera is equipped with an array of ultra-bright LEDs that capture the precise position of reflective passive markers in a predefined three-dimensional space. The performer wears a specialized suit and/or holds objects with reflective markers that are tracked by the motion capture system. This system for immersive DMI design allows the performer to move freely within an interactive space unencumbered by wiring and without the need of wearing mobile electronic components.

Miranda and Wanderley's taxonomy provides an excellent compendium of the possible forms of DMIs seen thus far in digital music performance. It should be noted that alongside the term "DMI", others appear in the discourse such as EMI (Electronic Musical Instrument) and VMI (Virtual Musical Instrument). I make use of Miranda and Wanderley's framework, and terminology, as it best achieves cohesion in the design approaches in this performance culture. Through an examination of the DMIs invented thus far, particularly alternate controllers, we see the interactive possibilities only now possible through digital technology. A heightened understanding of DMI designs, their interactive possibilities, and realized performance gestures further expands one's action-oriented ontology of digital musical performance for the layperson and practitioner alike.

Appendix B: Sensors and Software

Data Acquisition: Capturing Musical Gestures

Once a DMI designer has resolved the ways they wish to control sound through manipulating their instrument they employ sensors able to best capture those gestures. There are numerous types of sensors each having advantages when attempting to detect certain movements or interactions. Gesture capture and mapping strategies are present in all DMIs within Wanderley and Miranda's typology as these instruments do not function as intended by the performer without gestural data being acquired and passed along to the sound producing processes. Wanderley and Miranda explain data acquisition in DMI performance as occurring in one of three ways: *direct*, *indirect*, and *physiological* acquisition (Miranda and Wanderley 2006, 12).

Data obtained through sensors present in a DMI is referred to as *direct acquisition*. In other words, any gesture with a DMI that excites sensors to produce data to be used within the system. Direct acquisition accounts for the data generated within a DMI by physically manipulating the device. Sensors that are well suited to capture a performer's movements with, or physical force applied to, a DMI are generally simpler than indirect or physiological modes of data acquisition and are generally easier to comprehend as intentional musical gestures. Pushbuttons, mixing board sliders, potentiometer dials, accelerometers detecting physical orientation, and proximity detecting sensors typify gesture capture solutions that lend themselves to be easily perceived by audiences as musical gestures “directly” affecting sound output. Performance gestures captured using direct acquisition generally appear as immediately, or near immediate, responsible for a musical event. For the audience, this acquisition method is effective in clearly communicating musical intent and execution.

Indirect acquisition is the monitoring of produced sound created in performance. The authors claim that the only device capable of this type of acquisition is the microphone. Microphones can be integrated into a DMI to trigger musical events upon recognition of predetermined qualities of sound. Using software, performers can configure a DMI to track pitch, volume, and timbre of the outputted sound. Using digital audio processes such as an FFT (Fast Fourier Transform), software can detect a singular or a composite characteristic of the DMI’s sound and initiate events or behaviors as a result. Although the microphone is deemed the only possible sensor for indirect acquisition (Wanderley and Miranda 2006, 14), I interpret any device or computer process monitoring the output of a sound producing system as an additional means for musical control as belonging to this category of acquisition. The manner in which devices or components are used to collect data is paramount, rather than their type or form. Due to the nature of indirect acquisition occurring as a type of monitoring process, the musical material generated is obscure for audiences as deliberate actions to sound are unobservable. While indirect acquisition may be an efficient and effective means of triggering musical events, the lack of observable physical gestures place this type of data capture outside the boundaries of gesture analysis.

The last type of data capture considered is *physiological acquisition*. This type of acquisition accounts for sensors capable of monitoring human biological processes such as EEG (electroencephalography), GSR (galvanic skin response), and ECG (electrocardiography) signals; also referred to as *biosignals*. Physiological acquisition is the least common of these methods for a number of reasons. First, the data generated by the performer is difficult to make consistent. For example, if an ECG electrode is employed to monitor the heart rate of the performer to control specific parameters, unless the musician has a remarkable degree of control over that biological process, there is little guarantee that the data generated will be similar from performance to performance. However, if the artistic decisions made demand an improvisatory or indeterminate approach then physiological acquisition may be well suited. Another problematic aspect of using this type of data is that the signals generated tend to be of very low amplitude, making it pragmatically troublesome to interface this technology with consumer electronics or without medical grade monitoring machinery. Like indirect acquisition, biosignals can be difficult to observe, especially without any other feedback strategies in performance, as intentional musical gestures and in turn can be confusing for an audience. Well-calibrated physiological data is an excellent method for connecting performers, quite literally, to musical processes but is much more rare an approach in DMI design and performance culture.

There exist many components and methods of implementation for capturing gestures through data acquisition and is a necessary epiphenomenon of DMI performance. The functionality of a DMI depends on the ability of the system to capture physical gestures. The resolution of captured gestures determines how accurately a performer's movement can be translated to musical output. For example, if the data acquisition of a DMI utilizes the MIDI protocol the gestures captured will have a 7-bit resolution, or a range of 0 through 127 (it is an 8-bit protocol however the first bit is static). This can be problematic in transmitting the intricacies of expressive gestures with precision. Although the MIDI protocol will suffice in many circumstances, more accurate control can be achieved with transfer protocols such as Open Sound Control (OSC) or TCP/IP on LAN solutions. The options for data acquisition for digital musicians are continually expanding. However, considerations must be taken into account when routing data to the desired musical outcomes and the accuracy needed to successfully execute the artistic intent.

Mapping Strategies: Control, Behavior, and Observation

Once a gesture is captured as data, whether a push of a button or motion tracking of a conducting-like gesture using both arms, it must be *mapped* to a musical parameter within software, or another synthesis technique, for it to become sound. The process of mapping gesture to sound is the aspect of DMI culture that gives instrumentalists freedom to develop the interactive elements and instrumental mastery over a sound-producing device. Whether this comes as an advantage or obstacle to the individual performer is less important. What is salient is that DMI development offers musicians choice; how one's instrument will behave, adapt, sound like, look like, among other attributes largely static in other acoustic and DJ performing practices.

There are several different attributes of mapping strategies that define the behavior of the instrument and the resultant sound. The flexibility of digitally exclusive DMIs also comes with a considerable amount of needed organization within the software component of the instrument. This fact is naturally heightened when DMI designers choose to create the software component from scratch, but still applies when musical processes take place in commercial or preconfigured software. It is common practice to employ a DAW (digital audio workstation) to store pre-composed digital audio while the DMI functions as a method of initiating playback and/or manipulation processes. In either case, the designer develops the functionality of their instrument through mapping.

As a gesture recognized by a DMI becomes mapped to a musical parameter it takes on several characteristics. First, the DMI designer determines the number of parameters and type of musical function each gesture will control. The mapping also defines the type of gesture in regard to what is required physically of the performer to produce sound. And finally, the mapping takes on structural or formal qualities that create the overall composition of the performance. The mapping strategies utilized give the gestural vocabulary of a

DMI musical meaning and create a link between the embodiment of musical intent and the audience.

There is a considerable amount of research addressing the mapping of physical gesture within digital music making software environments. Wessel, Wright, Hunt, Kirk, Wanderley, Ng, among others, have analyzed mapping strategies that deal with the various, and often complex, methods of assigning the function of gestures in a DMI. The approaches for the construction and configuration of a DMI can vary to a great degree, and thus, so do the possible gestures and mapping strategies. While each of the above author's efforts attempt to be as comprehensive as possible, it remains difficult to develop an overarching analytical framework accounting for all types of DMIs. The gesture vocabulary of augmented instruments, instrument-like, and instrument inspired DMIs, resemble the acoustic instrument used or emulated in the design process. When analyzing alternate controllers, particularly in effort to expand the action oriented ontology of a non-practitioner, the gesture to sound mapping can be difficult to recognize.

An aspect of mapping that elucidates performance gestures for listeners is the correlation between physical movement and the number of parameters affected. Through an understanding of this essential design aspect the relationship between a performers body and the resultant sound can be observed more clearly. Andy Hunt and Marcelo M. Wanderley identify "three intuitive strategies" for mapping as:

a. *one-to-one*, where one synthesis parameter is driven by one performance parameter,

b. *one-to-many*, where one performance parameter may influence several synthesis parameters at the same time, and

c. *many-to-one*, where one synthesis parameter is driven by two or more performance parameters (Hunt and Wanderley 2002, 99).

The authors also identify the possibility of a many-to-many mapping, however this classification tends to muddle the clarity of embodied musical intent. The goal of this thesis is to frame DMI performing practice as an accessible art form, rather than offer a needlessly complicated mapping method that in all likelihood could be revealed as a combination of the first three methods. Understanding a DMI as numerous sound producing processes, each free to be controlled independently has been referred to as the *parametrical approach* for composing music (Miranda 2001, 12). This concept is revisited in the conclusion of this thesis, however it is pertinent to interpret DMI design as a method of controlling the perceivable elements of a musical composition using deviant methods. The parametrical approach illuminates how DMI designers must consider how musical parameters such as volume, articulation, pitch, timbre, structure, etc., will be controlled using physical gestures. Furthermore, this approach defines the shift in the psychoacoustics that has taken place for both the musicians and audiences of digital musical performance; this is especially the case for performances utilizing alternate gestural controllers.

The first approach identified by Hunt and Wanderley is mapping a single gesture to “one acoustic event or parametrical change” and represents the most simplistic method and easy to perceive as a musical gesture for audiences. Similarly, this mapping strategy is identified by David Wessel and Matthew Wright, in their article “Problems and Prospects for Intimate Musical Control of Computers” as present in acoustic instruments having mechanical linkages such as the piano or organ (Wessel and Wright 2002, 11). The familiarity of this mapping strategy, or its concept in acoustic instrument design, provides a familiar framework for audiences to grasp physical interactions with digital interfaces as intentionally sound producing.

The second approach, also referred to by Andy Hunt and Ross Kirk as “divergent mapping”, allocates one performance gesture control over multiple events or parametrical changes (Hunt and Kirk 2000, 234). Alike one-to-one mappings, this strategy can be easily perceived and understood by audiences due to the embodiment of an isolable physical expression as musical sound. Arguably, this mapping strategy is more easily recognizable than one-to-one mappings as these gestures, having control over multiple synthesis processes, change the overall aesthetic to a greater degree.

The final mapping strategy considered by Hunt and Wanderley, also defined as “convergent mapping” by Hunt and Kirk, accounts for assigning multiple gestures for the control of one parameter or acoustic event. Instances of mapping multiple gestures to one parametrical change are the most difficult to connect observed physical movement to musical outcomes within one's action-oriented ontology. Depending on the nature of the physical gestures required and the characteristics of the mapping, the required interaction can create gestures that reside far outside the boundaries of typical musical performance. Although these types of mappings are definitely capable of being musically effective, the complexity created in requiring multiple gestures for control over a single parameter can bring about difficulties for both performers and audiences. For performers, this type of mapping strategy often proves troublesome for accurately executing the combination of gestures for consistent musical outcomes. Similarly for audiences, combinations of gestures are difficult to associate with a single musical outcome.

As the above analytical framework explains how a performance gesture is mapped to parameters, the following tier explains the behaviors of the mappings themselves. A key trait of a mapping is whether it has "the ability...to evolve in time, to learn from the input over time." Mappings can be configured as *static*, performing the same musical function throughout performance. Conversely, a *dynamic* mapping can alter the function of a gesture to adapt, either "smoothly or abruptly", to trigger different musical processes as the performance progresses (Arfib et al. 2002, 131). According to the authors cited above, the behavioral characteristics of both static and dynamic mappings also operate within a *variation range*. This aspect of mapping relates to the physical limits a mapping defines for a particular musical gesture. The variation range affects gestural data by determining the area sensitive to gestural movement and thus determines the type of motor control required of the performer. The behavior of mappings adds an element of flexibility to the expressive possibilities of physical gestures with DMIs and creates a layer of interest in performances.

Another behavioral attribute of data mappings considered within this context describes the temporal aspects of the parameter under control. Gesture mappings can trigger generative musical processes or sustained sound output requiring a single gesture. In contrast, gestures can also be mapped to require continuous effort from the performer to maintain musical output. Todd Winkler explains the result of this aspect of mapping as the “predetermined and improvisational” aspects of digital musical performance (Winkler 1998, 28-29). Predetermined mappings, those requiring only momentary control to begin a musical sequence, also lie outside the action-oriented ontology of audiences as, once initiated, they sound without the need for gestural control. However, improvisational mappings, those requiring continuous physical input, create an observable link between the musician and musical output.

Lastly, this tier of the framework defines the formal and aesthetic control mappings within a DMI. The elements included are extracted from a larger examination of the aspects of HCI (Human Computer Interaction) observable in digital music performance as identified by Wanderley and Orio. In their article, *Evaluation of Input Devices for Musical Expression: Borrowing Tools from HCI.* Wanderley and Orio explore numerous mapping strategies, among other aspects of digital music performance, across many types of DMIs including dance interfaces and computer games (Wanderley and Orio 2002, 62-76). The highest-level formal aspect of a mapping strategy is *score-level control* (69). The use of this type of mapping affects the overarching or formal construction of a particular performance. Successively, are mapping strategies for *note-level control,* or “the real-time control of sound synthesis parameters, which may affect basic sound features such as pitch, loudness, and timbre” (69). This is also referred as “performer-instrument interaction” in reference to the real-time control of musical material within the formal structure of a performance. The last aspect identified by Wanderley and Orio is the sound *processing control* or *post-production activities* capable of DMIs, where the “digital audio effects or sound spatialization of a live performance are controlled in real time” (69). Aesthetic mappings, especially if improvisational, are also extremely effective for captivating audiences as they embody easily perceivable changes in sonority as physical interaction with an instrument.

The options available to DMI designers for capturing gestures and mapping data to musical parameters are not only vast, but also growing. Each sensor and software environment can also be used in various ways and to differing ends. This aspect of digital music performance design illuminates the difficulties for creating a standardized, and static, analytical framework. Due to the unpredictability present in DMI design, analyzing this performance practice is both complicated and perplexing. Notwithstanding, a comprehensive vocabulary for DMI design and performance is beginning to take shape in the discourse despite the hardware and software platforms under investigation. Furthermore, because DMI performance is preceded by historically rich acoustic performing practices, many of the physical gestures typically employed are rooted in acoustic practices. Certain combinations of data mappings, particularly those requiring minimal physical interaction from musicians, are more difficult to observe as embodied musical intent and execution. Yet, understanding the methods commonly used for assigning physical movement to musical processes within a DMI helps audiences in understanding the functionality of DMIs. As audiences become more versed with DMI design, they also become more able to relate perceived musical gestures with the processes they control. This brings DMI performance practice further within an audience's embodied imagination, and in turn their action-oriented ontology.

The Mechanical and Material Mappings of Acoustic Instruments

The process of mapping gestural data for musical performance is the key feature that sets DMI culture apart from acoustic practices. Many of the characteristics of the produced sound made by acoustic instruments are predetermined by the fundamental properties of the materials belonging to that instrument. Andy Hunt and Marcelo Wanderley have authored examples of mapping strategies occurring in several acoustic instruments in an attempt to demystify the mechanisms of DMIs through the familiar lens of acoustic instruments. To explicate the notion of mapping, Hunt and Wanderley offer the example of a piano keyboard as “only part of the playing interface” and a component of the instrument does “not directly contribute to the sound” (Hunt and Wanderley 2002, 97). A piano keyboard is part of the *key action mechanism* able to produce sound but does not produce sound on its own yet is an integral part of the musical outcome. As the keys are depressed in a modern piano a mechanical assembly is set into motion that, in short, simultaneously lifts a damper and propels a hammer into tuned strings producing a musical note. Depending on which key is pressed and how forceful it is excited determines the note sounded and the volume of that note. Therefore, each press of a key contains a “*one-to-many* mechanical mapping to pitch and amplitude”. In contrast to this example, the authors offer an instance of an “acoustic” *many-to-one* mapping. The volume control of a note played on a violin requires the performer to first use their fingering hand to shorten the length of the string (if required) and support the instrument in the playing position. Secondly, depending on the force the performer uses with their bow affects the volume of the note that will be produced. The acoustic mapping comparison also appears in the same issue of *Computer Music Journal* in an article titled “Problems and Prospects for Intimate Control of Computers” by David Wessel and Matthew Wright. However, while these authors recognize that when playing a piano “the connection between gesture and sound is mediated by a mechanical linkage...But the relationship between gesture and acoustic events remains in what one might call a "one-gesture-to-one-acoustic-event" paradigm" (Wessel and Wright 2002, 11).

These examples of *mechanical mappings* aim to elucidate the approaches DMI designers may take when configuring how their interactions will affect the digital sound producing processes. Hunt, Wanderley, Wessel, and Wright's analysis explores the notion of mapping strategies in acoustic instruments and could be applied to almost all categories in the above aggregate typology of mapping strategies except for those that account for generative processes capable only of digital technology. Here one could make the argument that the organ grinder, by turning the crank, is performing an acoustic example of an improvisational mapping, requiring continuous physical input, triggering predetermined musical events programmed and stored in the perforations in the cardboard feed read by the instrument. The mechanical "algorithms" in this instrument are static and the gestural vocabulary of the instrument, i.e. cranking the wheel (now usually accomplished by a small motor), is amusingly simple.

The goal of these types of comparisons is to place the collection of mapping strategies employed in a DMI into our action-oriented ontology. This makes perceiving the functionality of a DMI less difficult for those unfamiliar with the various approaches of DMI design. Physically, the inner workings are indiscernible; usually taking place within a computer or other "black box". Acoustic mappings are generally observable, even when predominantly hidden with the enclosure of the instrument such as a piano. However, if we imagine a pianist on stage seated at a grand piano, the lid would be propped open and the audience can observe a portion of the mechanisms in action. This notion contributes to deeming DMI performance as a mysterious or seemingly convoluted mode of making music, and has subsequently affected its inclusion in academic discourse.

Viewed through the multiple tiers of the above aggregate typology, digital music making shares much in common with acoustic performing practices and can be understood as an extension of that musical practice and culture. Thus, analytical approaches developed in the field of musicology can be suitable when analyzing DMI performance. Not only is the construction of DMIs relatable to acoustic instruments, but also the gestures used by digital music performers despite being developed using different materials.