Making Sensors Make Sense

Challenges in the Development of Digital Musical Instruments

by

Notto J. W. Thelle

THESIS

for the degree of

MASTER OF ARTS

University of Oslo

Department of Musicology

Faculty of Humanities

May 2010

Abstract

Despite the fact that digital technology has become an inevitable tool in music production and distribution during the course of the past few decades, live performers of digital musical instruments (DMIs) remain enigmatic to a majority of music audiences. A combination of instrument design issues, limits to the human cognitive system, and cultural constraints may all be contributing factors to these circumstances. This thesis presents a theoretical overview of some challenges in the development of DMIs, weighed against an empirical study based on qualitative research interviews with six DMI performers. Additionally, instrument types are categorized according to the *order of separation* between action and sound when performing with the instrument (*incorporated, direct, mechanical, analog electronic* and *digital*), and a hypothesis regarding the influence of instrument types on the music cognition of performers is tested.

Acknowledgements

I began working on this thesis nearly three years ago, and I find it hard to believe that I have finally made it through this rite of passage. It has, undoubtedly, been one of the most challenging and drawn-out experiences of my life. The combination of being a parent with a full-time job and writing a master's thesis on a challenging, interdisciplinary subject is highly recommended if you enjoy being under pressure. All in all, however, it has been a rewarding process, and I am thankful for having gained insights into a number of different scientific disciplines. Everything is music!

First of all, I would like to thank my supervisor, Alexander Refsum Jensenius, for valuable support. I find his knowledge and passion for research truly inspirational, and I am grateful for his wise evaluations of my work throughout the process of writing this thesis.

I would also like to thank my colleagues at NOTAM for sharing their knowledge with me on a daily basis. Unbeknownst to them, they have had considerable influence on this thesis. In particular, I would like to express my gratitude to Jøran Rudi and Rune Molvær for allowing flexible working hours.

A large part of this thesis is based on interviews with musicians. A big thanks goes to Natasha Barrett, Alex Nowitz, Maja Ratkje, Anders Vinjar, Rolf Wallin and Bugge Wesseltoft for participating, and also thanks to Anders Tveit for the pilot interview.

Finally, I would like to thank my wife, Kristine, for her kindness, strength and patience throughout this process; my parents for easing pressure on us by babysitting when I needed to focus on writing, and thanks to my son Leo, for being Leo!

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Chapter 1 – Introduction

This chapter presents the research goals, premises and limitations of this master's project, followed by an overview of the structure of the thesis.

1.1 Research Goals

The topic for my master's thesis is *digital musical instruments (DMIs)*. The main research question is:

- Why is it so difficult to develop DMIs for real-time performance?

From this main question, several sub-questions follow:

- What is a *DMI*?
- What constitutes a *comprehensible* DMI?
- What qualifies as *real-time performance*?
- Why is the development of such instruments important?
- Is it possible to formulate common goals that are applicable to all developers and performers of DMIs?

Despite the fact that digital technology has become an inevitable tool in music production and distribution during the course of the past few decades, live performers of digital musical instruments remain enigmatic to a large majority of music audiences. There is an element of distrust to be traced here. A major contributing factor to this distrust could be that it is difficult to understand what a DMI performer is doing. Often, the audience may not be able to determine whether what they are hearing is being performed on stage in real-time, or if it consists in the playback of prearranged sequences of music. I suspect this uncertainty could be alienating to many people.

In order to believe that something is being performed live, I think that the audience must either

- know the program that the instrument is running,
- understand how the program works,
- recognize at least some of the algorithms or functions used in the program, or
- witness consistent relations between the performer's actions and the sounds coming from the instrument.

Research communities and instrument developers have largely focused on the problems surrounding the inherent separation between action and sound in DMIs, and considerable resources have been invested in designing instruments that circumvent this separation in some way or other. Performers may choose to solve the problem by attaining a visual performance style that makes the relationship between action and sound seem more natural. However, all these efforts only seem to underscore a more important problem: *We lack a cultural context in which the use of DMIs in live performance can flourish.* The latter claim signifies an exploration ground on two fronts. It follows that in addition to developing new instruments, there needs to be a parallel development in composition, performance and perception of music in order for these instruments to have a context in which they can be fully appreciated. In this thesis, I will draw upon existing research and my own qualitative survey among six DMI performers to present the perspectives that have lead me to this understanding.

1.2 Definitions

I have adopted the term *digital musical instrument (DMI)* to denote a system containing a *controller*, a *sound engine* and the *mappings* between these units (Miranda and Wanderley 2006). The controller is the unit on which a performer plays, and the sound engine models the sound based on the digital representations it receives from the controller. The next chapter will be devoted to an in-depth investigation of these terms. I have generally avoided the terms *electronic instrument*, or its short form, *electronics*. The reason for this is that these terms fail to discriminate between *analog electronic instruments* and *digital musical instruments*. As will be made clear later in this thesis, the difference between these instrument categories is fundamental. However, several of my sources frequently refer to *electronics*, and in the context of citing these sources I have left the term unchanged. Unless specifically stated otherwise, the subject matter is DMIs when referring to *electronics*.

Making a DMI is not complicated per se. At its most basic, it is simply a matter of connecting any electronic sensor to a simple tone generator, for instance. However, such basic set-ups are not likely to yield particularly nuanced musical results. On the other end of the scale, very complex set-ups may seem meaningless if the audience does not know what is going on. A well-designed DMI must strike a balance between the obvious and the alienating. Complexity is not problematic as long as the instrument is *comprehensible* to an audience on some level or other. Something is comprehensible if it is possible to grasp the nature, significance or meaning of the object or concept in question. The issue of comprehensibility does not apply to most acoustic instruments, because understanding the nature of vibrating physical objects set into motion by mechanic forces is an ingrained part of our perception (Clarke 2005). I will shed more light on the topic of human perception in Chapter 3. In the case of acoustic instruments, our inheritance and life-long experience with the laws of physics tends to make acoustic instruments comprehensible on an intrinsic level. We know, for instance, that beating an object tends to cause a percussive sound—another sonic result would be very surprising to our senses. Of course, there are cases where a performer of an acoustic instrument can confuse the audience by producing sounds that are unexpected from the instrument he or she is playing. Still, the performer's actions and the sounds are so inextricably coupled that there is seldom any doubt about the relationship. With DMIs, however, the only physically vibrating audible objects are the speakers of the sound engine. Unless we know something about the operations triggering the movement of the speakers, it is difficult to make sense of what we are hearing. That is not to say that the sounds cannot be appreciated for their aesthetic qualities in their own right; schema-free appreciation, however, does require a bent for less traditional ways of perceiving music. As we will see, making sense of digitally produced sound can take on many forms.

I have chosen to narrow down my research question further by applying it to DMIs for *real-time performance*. This is an important, but problematic demarcation. DMIs are ubiquitous in many music genres, but they are very commonly performed by means of triggering preprogrammed sequences of sound. Such performances typically consist of adding effects to or spectrally filtering the preprogrammed material. In this thesis, I am mainly interested in digital musical instruments used for "sculpting" sounds in real-time, either through live sampling or by means of sound synthesis. The absence of real-time DMI performance in the so-called mainstream is noteworthy, especially considering the fact that virtually every link in the chain of music production relies heavily on digital technology. However, classifying real-time and non-real-time performance is not straightforward. We are dealing with a continuum between sound engineering and live performance (I will discuss this further in Chapter 4).

I would like to add that some topics relevant to this thesis have been omitted. For example, the research field of *gestures* in music, or *music-related actions*,[1] is becoming an important field of research, but is not discussed. Furthermore, research related to the sense of touch, body position and motion—*haptics*—is another topic that has fallen short of being included in this thesis. These topics are equally important to the field of DMI development as the ones I have chosen to focus on. However, my intention is not to provide a complete overview of all the fields that are relevant to DMIs. I feel that my research questions are better answered by focusing in depth on a few topics, rather than attempting to account for all research related to DMI development.

1.3 Structure

This thesis is based upon research from many different disciplines such as *musicology, philosophy, psychology, biology, cognitive neuroscience* and *human–computer interaction (HCI)*, and on interviews with performers of DMIs. The scope of the thesis cannot give a comprehensive insight into all these disciplines. However, I hope the curious reader will be moved to investigate my sources further, and I have tried to collect the threads and present them in a fashion that enables the best possible

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[1] For more information about this research field, the publication *Musical Gestures. Sound, Movement and Meaning* is a good starting point: http://www.routledge.com/books/details/9780415998871/

overview. The thesis is divided into two main parts: *I: Theory,* and *II: Empirical Study*.

Part I: Theory

These chapters give an overview of DMIs and the theoretical perspectives that have shaped my current understanding of the challenges facing developers and performers of DMIs.

Chapter 2 is devoted to an analysis of DMIs and related terms such as *controller, mapping, sound engine, sensor, sound synthesis* and *sampling*. It presents two common communication *protocols*, *MIDI* and *OSC*.

Chapter 3 presents the human cognitive system viewed from an *embodied* perspective. With roots in *ecological psychology* and supported by research in the field of *cognitive neuroscience*, this chapter shows how *embodied music cognition* may contribute to a deeper understanding of the link between the performance and perception of music. The concepts presented in this chapter may be helpful for the field of DMI development in the future.

Chapter 4 turns the focus toward the cultural significance of new technology, and presents a classification system based on the *order of separation* between action and sound in the performance of the instruments: *incorporated, direct, mechanical, analog electronic* and *digital*. These categories are the vantage point for the empirical study in Part II.

Part II: Empirical Study

The chapters in this part are focused around the findings of an empirical study I conducted through qualitative research interviews with six different performers of DMIs. These performers are also expert performers of various non-DMI instruments, allowing for valuable comparisons between the instrument categories presented in Chapter 4.

Chapter 5 provides a review of the methodological approach I adopted in the empirical study, and continues by going through the qualitative investigation process in seven stages.

Chapter 6 briefly reviews the hardware and software that is featured in the empirical study, and presents the backgrounds of the respondents and their DMI configurations in detail.

Chapter 7 is an analysis of the findings based on transcriptions of the qualitative interviews. The findings are presented along the lines of some main themes that crystallized out of our conversations: *Developing the Instrument and with the Instrument, Operating in Different Domains, Performing with the Instrument* and *The Future*.

Discussion & Conclusion

Chapter 8 provides a summary of the thesis, compares the empirical findings with the theory in Part I, comments on the relevance of the results, reflects on the research process and points out possible areas for further research.

Part I

Theory

Chapter 2 – Digital Musical Instruments

This chapter gives an overview of DMIs and their components, and presents research relevant to these topics. Taking my cue from Miranda and Wanderley (2006) and Jensenius (2007), I will use the term *digital musical instrument* (DMI) to denote a system containing a controller on which a performer plays, and a sound engine that bases itself on digital representations of the control outputs. Both are independent modules related to each other by mapping strategies (Miranda and Wanderley: 3).

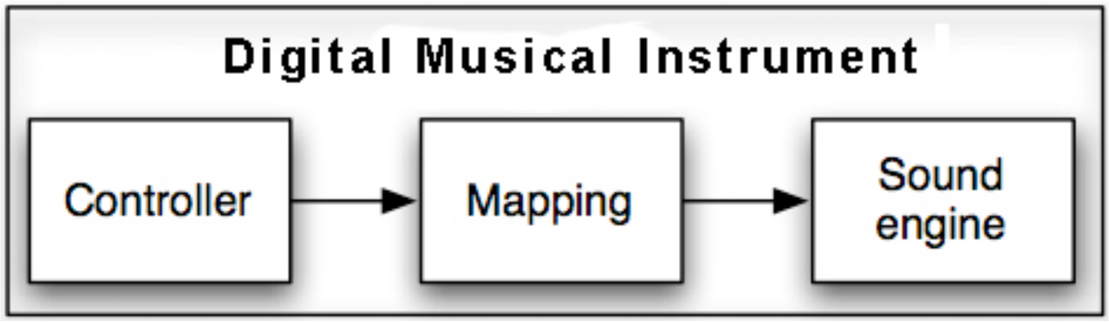

Figure 2.1. A digital musical instrument consists of a controller mapped to a sound engine.

2.1 Sensors

The Merriam-Webster Online Dictionary defines a *sensor* as “a device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control)”. This definition could include a wide variety of devices with any kind of usable output. For instance, a mercury thermometer converts measured temperature into expansion and contraction of a liquid that can be read on a calibrated glass tube. In the context of DMIs, a sensor is a device that measures corporeal action, and which produces output in the form of electrical signals. These signals are then converted into appropriate digital signals (Miranda and Wanderley 2006: 103–104).

The choice of sensor type or types in a controller depends on the desired functionality. Among the most widely used sensors are:

- *Force-sensitive resistors (FSRs)*. Electrical output increases with increased applied force.
- *Strain gauges*. Resistive elastic sensors whose resistance decreases with compression and increases with tension.
- *Bend sensors*. Bending the sensor increases the resistance.
- *Potentiometers,* colloquially known as *pots*. *Sliders* are linear pots and *knobs* are rotary pots. Voltage output can be varied depending on slider or knob positions.
- *Proximity sensors* detect the presence of nearby objects without any physical contact, and can be used to detect motion (on/off) or measure distance between the sensors and the sensed object (variable voltage output).
- *Accelerometers* measure movement experienced relative to free fall and can be used to detect magnitude and direction of the acceleration as a vector quantity. Commonly used to sense orientation, vibration and shock. Several accelerometers can be mounted at angles of 90° in order to obtain measurements of acceleration in multiple axes (often referred to as dimensions, e.g. *3D accelerometer*).
- *Gyroscopes*, or *gyros*, measure angular velocity and can be used to detect the rotation of devices in which they are implemented.
- *Air pressure sensors*. Commonly used to measure breath pressure. Voltage output varies depending on the magnitude of air pressure.
- *Contact sensors*. Naturally, most electronic devices offer simple on/off functionality, usually activated by *tactile switches* (buttons) or other types of touch sensing.

The sensors mentioned above have in common that they require some form of overt, deliberate action by the operator (body movement, shifting of postures or orientation). Alternatively, there are medical sensors that can monitor biological phenomena occurring in the body, so-called *biosignal interfaces* (ibid. 173–215), which measure corporeal *re*action. Examples are devices that measure *galvanic skin response (GSR)* to detect emotional arousal, or *electroencephalography (EEG)* devices that measure brain waves. A few musical performers have integrated various biosignal interfaces in their set-up.

This overview of sensors used for musical purposes is by no means exhaustive, but is a useful backdrop for the following chapters.

2.2 Controllers

A *controller* is the interface that the performer uses to send signals to the sound engine. It can also be referred to as a control surface, a gestural or performance controller, an input device or a hardware interface (ibid. 3). Any device that contains a *sensor* or *sensors* that can pick up a performer's actions, movements or body states and transduce these to signal or data outputs can be used as a controller. A controller can be specifically designed for integration in a DMI. A typical example is a standard MIDI keyboard controller. However, it has become exceedingly common for musicians to use controllers originally designed for other or generic purposes, such as computer keyboards/mice or game controllers, or to custom-build controllers by incorporating sensor technology from various scientific fields. Possible reasons for this shift and its implications will be discussed later.

Since the advent of the MIDI protocol in 1982, the number of controllers for DMI implementation has increased dramatically (Piringer 2001). There have been relatively few attempts to provide a comprehensive review of the full range of controllers available. Miranda and Wanderley (2006) have made a notable contribution towards the categorization of DMI controllers. Here, they argue that the various existing controllers can be studied from different points of view depending on how one chooses to classify them. They opt for a review of controllers based on their resemblance to existing acoustic instruments, dividing them into four different categories. It is important to note that these categories should be seen as a continuum ranging from actual acoustic instruments with extra sensing capabilities to devices that are entirely unlike existing instruments.

- *Augmented musical instruments* are acoustic (sometimes electric) instruments equipped with various sensors. Performers are thus provided the ability to control extra sound or musical parameters, enhancing the original instrument's functionality and sonic qualities. A recent example of an augmented musical instrument is a violin used in combination with an *electronic violin bow* developed by NOTAM [2] in collaboration with the Norwegian Academy of Music for the violinist Victoria Johnson (Guettler et al. 2008). A small circuit board equipped with 3D accelerometers, 2D gyroscopes, switches for program control and a pressure sensor has been placed at the frog of the bow. The violinist can thereby control data using a combination of violin bow actions and the pressing of buttons while playing.

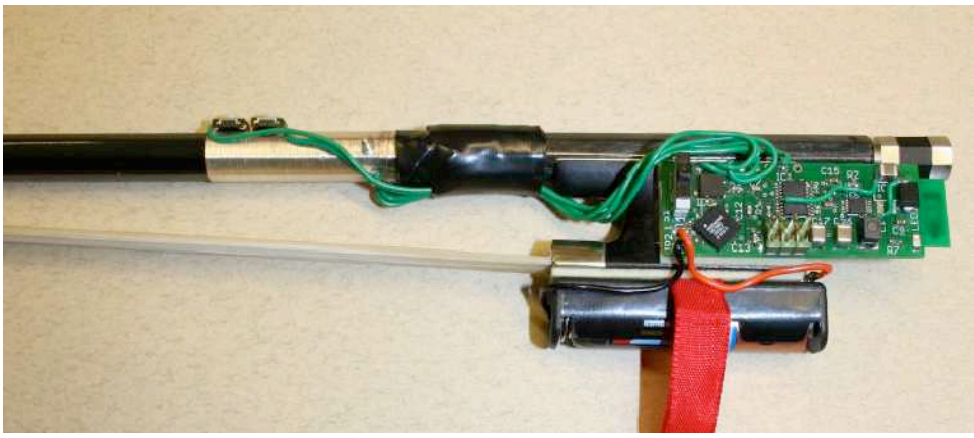

Figure 2.2. Electronic violin bow. Photo: Hans Wilmers.[3]

- *Instrument-like controllers* are modeled after the control surfaces of acoustic instruments, with the goal of reproducing their initial features (Miranda and Wanderley 2006: 20). So far, commercial instrument manufacturers have mainly relied on the production of such controllers, with keyboards being the most obvious example. Typically, controller keyboards of high quality have weighted keys that simulate the mechanical resistance of piano keyboards, adding a sense of "reality" for performers that are used to playing the piano. Equivalent features are to be found in other instrument-like controllers, such as various wind controllers (synchronized tongue, breath and finger control) and digital drums (vibrating membranes that accurately register the performer's actions while providing natural mechanical feedback).

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[2] Norwegian Center for Technology in Music and Art

[3] http://www.notam02.no/index.php?/eng/Teknologi-og-tekst/Maskinvare/Sensorbue

Figure 2.3. Roland’s V-Drum series provides controller drums with membranes (so-called mesh-head triggers) that are surprisingly realistic compared with acoustic drums. V-Drums are sold complete with “drum brains” (sound engines), and are therefore by definition DMIs. Photo from http://www.roland.com.

- *Instrument-inspired controllers* are inspired by the control surfaces of existing instruments, but unlike instrument-like controllers, they do not seek to reproduce all of their features (ibid. 27). Often, attempts are made to overcome the limitations of the original instrument while the overall vocabulary of performance-related actions is preserved. Various keyboard controllers, for instance, have provided performers the ability to glide between notes or to control the timbre of an already played note – actions which are impossible on a piano. Other instrument-inspired controllers are used in a more general sense and can be substantially different from the instrument they are modeled on. However, what controllers in this category have in common is that their design enables access to performers who are familiar with the instruments they are inspired by.

Figure 2.4. The *Continuum Fingerboard* from Haken Audio has a control surface inspired by the piano. As its name implies, the board enables continuous pitch control over 8 octaves, and a performer can also control the timbre of each struck note by sliding fingers in the so-called y direction (front to back). Photo from http://www.HakenAudio.com/Conituum.

- *Alternate controllers* are not directly modeled on or necessarily inspired by existing acoustic instruments (ibid. 30). Basically, any controller that does not fall into the above three categories is an alternate controller. Miranda and Wanderley adopt a classification system provided by Axel Mulder to further subdivide alternate controllers into three categories: *touch controllers, expanded-range controllers* and *immersive controllers* (ibid. 31). *Touch controllers* have a physical control surface that the performer operates. JazzMutant's *Lemur*, for instance, is a multi-touch and modular controller for sequencers, synthesizers and virtual instruments. *Expanded-range controllers* may or may not require physical contact, but have in common that there is a specifically defined range of actions that yield musical results. Outside the sensing field, the performer can move without musical consequence. An early example of an extended-range controller is *The Hands*, created in 1984 by Michel Waisvisz (a second version was created in 1989 in collaboration with Bert Bongers). A wooden frame equipped with various sensors and buttons is worn by the performer on each hand, providing extensive means of control through a combination of hand tilting, arm movements and fingered playing. Finally, *immersive controllers* place few or no restrictions on performer movements, and the performer is within the sensing field all the time (ibid. 31). Various data gloves, such as Laetitia Sonami's *Lady's Glove* (developed by Bert Bongers), can be considered partially immersive, whereas fully immersive controllers include various body suits or motion capture systems. *The Hands* cannot be considered partially immersive because, despite its name, the shape of the device is not identical to the shape of the hands (ibid. 41).

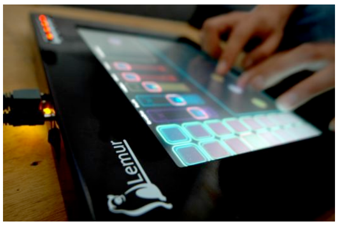

Figure 2.5a.

Touch

The *Lemur* multi-touch controller from JazzMutant. Photo from www.jazzmutant.com

Figure 2.5b.

Expanded range

Michel Waisvisz' *The Hands*. Copyright: mwais/crackle.org

Figure 2.5c.

Immersive

Laetitia Sonami's *Lady's Glove*. Photo: Andre Hoekzema

The controller is an important part of a performer's visual expression. It is the device with which he or she interacts; it is the DMI component that the audience can see. It is interesting to keep this in mind as we continue. Controllers do not make sounds; they mediate information.

2.3 Sound Engines

A *sound engine* is the output unit of a DMI, and includes both the *sound generation* and the *playback* units. The *sound generation unit* consists of *software* (a program or a collection of programs) and *hardware* (computers, synthesizers or other signal generating devices). Most sound engines are either computers running specialized software, software programs integrated in hardware controllers, or external *synthesizer* or *sampler modules* that can be controlled via a *communications protocol* (usually MIDI, described later). The *playback unit* of a sound engine consists of a *digital to analog converter (DAC)* and one or several speakers.

Roughly summarized, there are two main methods of working with sound in the digital domain. In *sound synthesis*, sounds are engineered from a set of fundamental building blocks or algorithms. With methods based on *sampling*, external sounds are recorded and stored in the memory of the software program. When extracted from the memory *(buffer)*, these sounds can be transformed through *digital signal processing (DSP)* methods. Quite easily, the transformations could become so complex that the sounds end up bearing little relation to the original sound source.

Theoretically, the difference between sound synthesis techniques and sampling-based methods is not clear-cut. In fact, all digital sound consists of *samples*; however, a source of confusion is that we are dealing with two separate definitions of the term *sample*. In DSP, a sample refers to a value or set of values at a point in time and/or space. In musical terms, a sample is a short recording or portion of a recording – a block of sound. Using the DSP version of the term, we can say that sound waves are represented digitally by samples (the norm is 44,100 samples per second – a *sample rate* of 44.1 kHz). Sticking with this definition, digital sound synthesis is the process of generating streams of samples by algorithmic means (Roads 1996: 46). When referring to a performer who *samples*, however, it is generally understood that he or she works with transforming blocks of recorded sound (on the time scale of seconds). In this context, each block of sound is referred to as one sample (which actually consists of thousands of [DSP] samples). The smaller these blocks of sounds are, the more a performer's working techniques resembles actual sound synthesis, especially when the recorded chunks are split into pieces on the scale of milliseconds and restructured algorithmically. This is what happens in a borderline case of sound synthesis/DSP called *time granulation*. The meaning of this will become clearer below, as I review some of the most normal sound synthesis techniques. In practice, there is a degree of overlap between the two working methods. All the same, it is a useful distinction because performers often define themselves as mainly working with one method or the other. In sum, a rule of thumb could be that sound synthesis is the process of building sound, while sampling relates to the practice of using recorded acoustic events as a vantage point for sound experimentation.

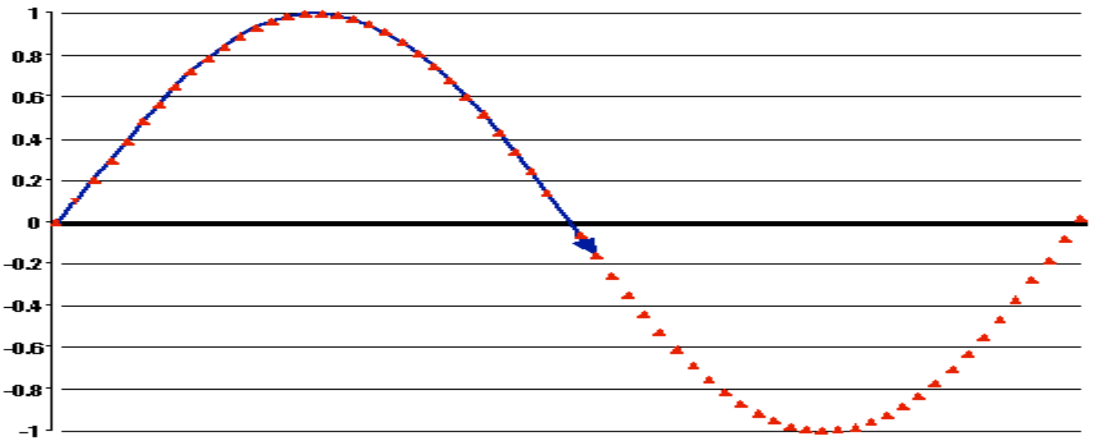

Figure 2.6. A simple sine wave, represented digitally by a number of *samples* (in the DSP sense of the word).

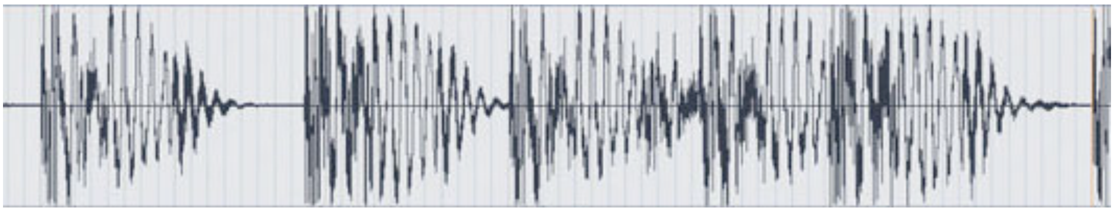

Figure 2.7. Screenshot of waveforms in a computer program. These waveforms are a visual representation of a sample (as in a block of recorded sound), and consist of thousands of (DSP) samples. If the waveforms are split into thousands of pieces, they become subrepresentations of sound—more like (DSP) samples. This illustrates the fuzzy boundary between synthesis and sampling-based techniques in sound engines.

Sound synthesis techniques

Below is a short review of the most common sound synthesis techniques.

- *Additive synthesis* is the process of combining sine waves at various frequencies to create more complex waveforms. The concept dates back several centuries to when *register-stops* were implemented in pipe organs, providing variations in the timbre of a note by routing air to different sets of pipes. The theoretical foundation for additive synthesis was laid by the mathematician Joseph Fourier (1768–1830), who proved that all periodic functions (including sound waves), when represented as a mathematical function, could be composed as a sum of sine functions of various frequencies. In theory, it is thus possible to approximate any complex waveform as a sum of elementary waveforms. However, the creation of complex waveforms using additive synthesis demands a lot of processing power compared with most other synthesis techniques (Roads 1996: 134–144).

- *Subtractive synthesis* is the process of applying various filters to harmonic-rich source signals. The source signals are created by different types of waveform generators *(oscillators)*. If the source signal is spectrally rich and the filter is flexible, subtractive synthesis can be used to approximate naturally occurring sounds as well as create new timbres. Among the most usual source signals are *sawtooth, square, pulse* and *triangle* waves. These *non-sinusoidal* waveforms (not pure sine waves) have in common that they contain broad ranges of frequencies, providing many possibilities of shaping different timbres by removing selected regions of the frequency spectrum (filtering). It is common to apply further modulation by using *low-frequency oscillators (LFOs)* to control various aspects of the overall signal, such as amplitude (tremolo) or pitch (vibrato), or to vary parameters within the filters (ibid. 184–197).

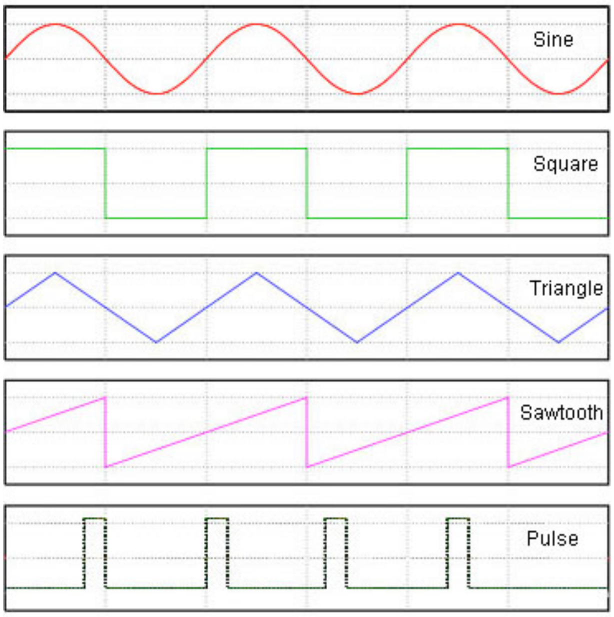

Figure 2.8. Depictions of typical waveforms created by oscillators.

- In *frequency modulation (FM) synthesis*, the frequency of an audio signal generated by one oscillator (carrier) is varied at a rate and depth defined by another oscillator (modulator). FM of electromagnetic waves has been used in radio broadcasting since early in the 20th century. In the early 1970s, John Chowning at Stanford University experimented with FM of audio signals, and discovered a whole range of complex timbres that would demand powerful and extensive tools if derived by other synthesis techniques. This low cost in computational power made it feasible to vary complex timbres over time, making them dynamic and sound more animated. FM synthesis provides ample opportunity to approximate sounds created by musical instruments, such as strings, horns and reeds, glasslike and metallic sounds, or a wide range of more electronic sounding timbres. After systematically exploring the technique, Chowning developed a patent on an implementation of FM, which the Japanese Firm Nippon Gakki (Yamaha) obtained a license for. In 1983 and several following years, Yamaha's *DX7 synthesizer*, which featured Yamaha's further development and refinement of Chowning's original technique, made such an impact on the music industry that it became a major influence in the sound of pop and rock music of the 1980s. Stanford University's FM patent expired in 1995, and FM synthesis is now one of several techniques included in most modern synthesizers (ibid. 224-250).

Figure 2.10. The DX7 synthesizer from Yamaha.

- *Wavetable synthesis* bases itself on looking up lists of values that represent single cycles of any waveform. The waveform could be based on a sample of a real instrument or naturally occurring sounds, or may be constructed using other synthesis methods. Such a list of values is called a *wavetable*. The size of the wavetable (the number of values) is typically a power of two: 64, 128, 256, 512, etc. Table lookup is the core operation of a digital oscillator. At its most basic, wavetable synthesis reads through one wavetable repeatedly and continuously sends the values to the playback unit. The result is a static timbre, which is not particularly well suited for musical contexts. Several methods have been developed to create sounds that vary over time. In *wavetable crossfading*, the oscillator crossfades between multiple wavetables over the course of an event. Alternatively, *wavetable stacking* or *wavestacking* is the layering of multiple wavetables. The latter is similar to additive synthesis; however, in contrast to additive synthesis where each component is a simple sine wave, the wavetables used in wavestacking could be a cycle or even a longer segment of any complex waveform. These methods can yield dynamic, deep and rich hybrid textures (ibid. 159–163).

- In *granular synthesis*, sound is viewed as consisting of small particles of sonic energy, *grains*, as opposed to the collection of sound waves at different frequencies. A sound grain is a very short burst of sound (typically 1 to 100 milliseconds), and could be based on sampled material or synthesized sound. Sampled sound sources are not used in a direct manner; using a technique called *granulation*, the sounds are split into grains and rearranged algorithmically. Grains may be layered on top of each other playing at different speed, phase, volume and pitch. As a result, granular synthesis is often characterized by "cloudlike" sounds: complex soundscapes quite unlike the sounds produced by most other synthesis techniques. It is important to note that granular synthesis is not *one* technique: rather, it constitutes a range of different DSP techniques that share only the concept of sonic grains (ibid. 168–184).

- *Physical modeling synthesis* is a family of synthesis techniques where the waveform of the sound to be generated is governed by a mathematical model consisting of equations and algorithms that describe the mechanical and acoustic behavior of a physical sound source. Thus, if the physical behavior of a sound source – a musical instrument, for instance – is well understood and can be accurately described in a mathematical model, the use of this model to generate sound results in a very realistic rendition of the sonic qualities of the sound source. By changing parameters within physical models, one can experiment by creating sounds of fanciful instruments that would otherwise be impossible to build. This could include, for instance, expandable and shrinkable instruments, building-size "guitars" with strings as long and thick as bridge suspension cables, instruments whose construction materials are constantly changing, etc. Because physical models are based on (often simplified) laws of nature, they excel at capturing non-linear characteristics of acoustic instruments, reproducing “accidents” that may occur in performance, such as squeaks, mode locking and mulitphonics (ibid. 265–288).

Many of the above synthesis methods (those whose sounds are generated by oscillators) result in a continuous sound, which is not very practical in musical contexts. By applying an *amplitude envelope* that varies as a function of time, more musically interesting sounds can be created. A so-called ADSR envelope has been much used in sound synthesis, especially for keyboard controllers. ADSR is an acronym describing four stages of the overall amplitude of a triggered sound: *attack* (the time it takes for the sound to reach its peak amplitude from a starting point of zero), *decay* (the time it takes from the attack level to the designated sustain level), *sustain* (the amplitude of the sound during the main sequence of its duration) and *release* (the time it takes for the sound to decay from the sustain level to zero). The length of the sustain stage depends on the controller input. It is held until a key is released, for instance, on a controller keyboard. There are, however, envelope editors that are more flexible than the relatively simple ADSR model. Today, it is becoming more common for musicians to define their own amplitude envelopes by tracing arbitrary curves (ibid. 97).

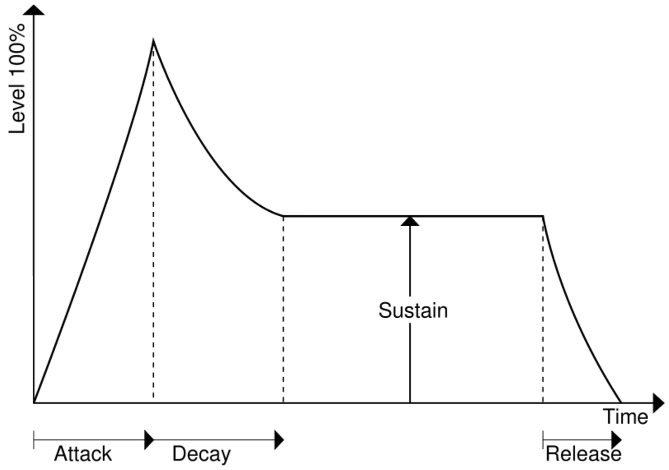

Figure 2.11. An ADSR envelope.[4]

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[4] http://courses.cit.cornell.edu/ee476/FinalProjects/s2009/jvt6_th389/jvt6_th389/finalproject.html

In sum, sound synthesis is a complex scientific field, demanding years of study and experimentation. This fact is not lost on manufacturers of synthesizers. Most synthesizers feature a wide range of factory presets containing sounds that have been carefully developed by the manufacturers. Arguably, a majority of digital synthesizer users rely mainly on such presets instead of creating their own sounds from scratch. Thus, an approach familiar from organ playing (switching between predefined sounds) has survived into the realm of DMIs. This may be one reason why the keyboard became – and still is – such a ubiquitous controller in DMI configurations.

DSP operations for transforming sound

As mentioned earlier, the terms *sample* and *sampling* are used interchangeably to describe different phenomena within DSP and music making. From this point on, I will refer to a sample as a block of recorded sound, and by sampling I am referring to the practice of recording sound with the aim of playing it back in musical contexts. My particular area of interest is the active creation of new sounds by transforming the sampled material through the use of various DSP operations. These methods differ from the more traditional DJ methods of representing the samples (often a loop from songs by other artists) relatively unchanged, but in novel settings and arrangements. While the latter could be seen as leaning toward sound engineering or composition, the former features an approach characteristic of musical instrument performance.

Below are some examples of typical operations that can be used to transform sampled material. I will not delve into the technicalities behind the operations. I focus on DSP operations that transform the whole audio signal as opposed to *audio effects,* i.e. sending a portion of a signal via an auxiliary route to be modified (often in a time-based manner) and mixing it back in with the original signal (White 2003: 19). Thus, standard delay-based effects such as *reverb, echo, chorus, phasing* and *flanging* are not featured here.

- *Filtering*. Rejecting, attenuating or boosting selected regions of the sample's frequency spectrum.
- *Distortion*. Clipping the shape of the waveforms by various methods, often resulting in harsher or more aggressive versions of the original sound.

- *Modulation*. Using an oscillator to modulate various aspects of the sample (which functions as the carrier signal), e.g. *ring modulation, phase modulation, amplitude modulation, frequency modulation*, etc.
- *Pitch shifting*. Changing the overall pitch of the sample.
- *Time stretching/compressing*. Playing the sample back at different speeds without affecting the overall pitch.
- *Reversing*. Playing the sample backwards.
- *Morphing*. Interpolating between two or more samples, creating a smooth transition between unique timbral qualities.
- *Convolution*. Computing the integral of the product of the waveforms of two samples. The result is typically a modified version of one of the original samples as "articulated" by the other (e.g. "a trumpet playing the piano", "a waterfall speaking", etc.).
- *Granulation*. Already described above, this is an operation that borders on actual sound synthesis.

Naturally, synthesized sounds may also be transformed by DSP operations. Processing is particularly important for performers who work with sampling, however, because by radically transforming the sampled material, the artists become sculptors of novel sounds on the same level as performers who work using pure sound synthesis techniques.

Types of sound engine

Above, I have only described general synthesis techniques and a few typical DSP operations. A comprehensive review of specific sound engines is beyond the scope of this chapter. However, a rough overview is possible by dividing sound engines into three main categories: *computers with installed software, sound engines integrated in controllers* and *hardware modules*.

- *Computer software*. In a computer, any of the above methods of sound generation and/or processing are possible as long as the appropriate software is installed. Computer software for music and sound is difficult to categorize. Figure 2.12 is one way of differentiating between different types of software functionality. Some programs are specialized within narrow application areas; some are extensive tools that reach over a wide area of functions, while others yet are so-called *plug-ins* (programs that are designed to serve specific functions within a host application).

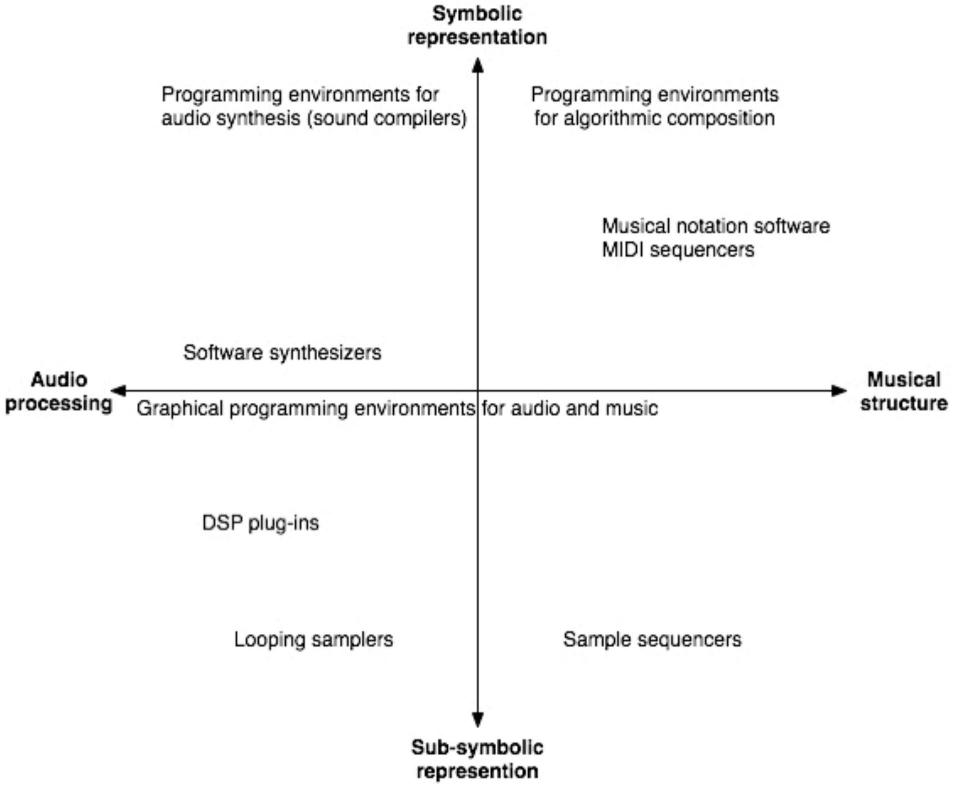

Figure 2.12. An overview of different types of software functionality, based on my own categorization. The horizontal axis is a continuum ranging from software designed for audio processing and/or synthesis purposes to software designed for working with musical structure. The vertical axis tells us something about how the working material is represented. Programming languages and various kinds of musical notation systems are defined as *symbolic representations*, whereas the visualization of sound waves and frequency spectra are *sub-symbolic* because they represent the actual sound.

The combination of host software and plug-ins can create massive working environments that feature functionality along the entire range on both the above axes.

- *Sound engines integrated in controllers*. Ever since the introduction of the MIDI protocol, designing controller and sound engine as an entity has become gradually less common. Musicians of the past few decades have shown a clear preference for the flexibility provided by separate controllers and sound engines. Meanwhile, many innovations by instrument manufacturers in this field have fallen flat. A possible reason for this is that many musicians dislike having their choices dictated and their range of experimentation limited by hard coded programming. Arguably, keyboard synthesizers are one of the very few truly successful (in terms of sales) complete DMI units. With their relatively long tradition extending back to the early age of analog synthesis, keyboard synthesizers are probably ensured longevity as a classic category of instruments. However, they all feature MIDI outputs, so they can, by choice, be reduced to mere controllers by bypassing the internal synthesizer.

- *Hardware modules*. If not using a computer workstation or laptop on stage, most DMI performers rely on external special-purpose hardware to perform sound generating operations. As with sound engines in general, these devices can be roughly divided into *synthesizer* and *sampler modules*. Some devices feature both synthesizing and sampling functionality. External hardware modules are mostly designed with a narrower range of applications than computer software. In return, they are generally less prone to bugs and operation failures under stress than programs running on computer operating systems. Choosing between working with external hardware components or computers is also an aesthetical question; from my own experience, some musicians wish to avoid being labeled as "computer musicians who stare into a screen onstage". Although this is an unsubstantiated fear (computers can be hidden away), computers do still have a bad reputation for being less reliable in performance. Hardware modules are designed with one purpose in mind, music; manufacturers are therefore faced with strict demands from users in terms of user-friendliness, operability and reliability. They know that defects cannot be attributed to anything but their own product.

The sound engine is what produces the sounds that the audience hears. However, the concept of sound engines can be enigmatic to many people who do not have direct working experience with digital sound. Often, the only reliable reference is what they can see. The audience sees a performer playing with a controller, and can deduce that this is the person creating the sounds by matching his or her actions, posture and other expressions with the sounds. This relatively weak link is why *mapping*, the topic of the next section, is important

2.4 Mapping

Mapping from controller to sound engine is a crucial aspect in the development of DMIs. One of the main challenges in mapping is the discrepancy between available control parameters and the great number of parameters within the sound engine. This is particularly the case for sound synthesis with its bottom-up approach. As we have seen, there are, theoretically, very few limits to the kinds of sounds that can be programmed. The human performer, however, cannot possibly maintain a conscious awareness of all possible parameters in real-time performance. *One-to-one mapping* – the mapping of one type of action to control one parameter – could in many cases be an ineffective mapping strategy for music performance, unless the amount of parameters to be controlled is limited and well defined. Furthermore, many parameters within sound engines (e.g. oscillator frequencies, waveforms, modulation amplitudes, etc.) are not directly correlated to any perceptual qualities (Jensenius 2007: 101). In acoustic instruments, several parameters are usually *coupled*.

> For example, the breath input in a clarinet may control the timbre, loudness and vibrato of the sound at the same time. Similarly, the sound parameters may also be controlled by lip pressure (ibid. 101–102).

Jensenius refers to this as an example of what may be called *many-to-many mapping*. Most acoustic instruments seem to be based on many-to-many mappings and the couplings between these. Studies have shown that performers tend to prefer such coupled mappings between a few output and input parameters to other mapping strategies (Hunt et al. 2003).

Miranda and Wanderley (2006: 15–16) describe two main directions in mapping:

- *Explicit mapping strategies*. Here, the relationships between a performer's various actions and the sound parameters are explicitly defined. Within this direction, several strategies can be devised: o*ne-to-one* (one sound parameter is driven by one action parameter), *one-to-many* (one action parameter may influence several sound parameters simultaneously), *many-to-one* (one sound parameter is driven by two or more action parameters) or *many-to-many* (a combination of the above basic strategies). Defining relationships between specific action and sound parameters is a great challenge. As we will see in the next chapter, human perception is molded by evolution and development to function in a specific way, and this dictates what is generally regarded as intuitive action–sound relationships (Jensenius 2007). Hence, it is no surprise that many DMIs end up using fairly obvious action "vocabularies" to control perceptual qualities such as pitch and amplitude (e.g. upward motion for high pitch and high amplitude, downward motion for low pitch and low amplitude).

- *Model-based mapping strategies* use machine learning techniques such as neural networks, feature extraction or pattern recognition as tools to perform mapping. This direction features methods where mapping strategies are devised by means of internal adaptations of the system through training or the selection of most important features among the set of signals (Miranda and Wanderley 2006: 15). Jensenius (2007: 101) reviews several model-based solutions provided by researchers in the past decade. One approach is creating mappings from a low-dimensional control space to the multidimensional sound model, for example by assigning groups of parameters that work well together *(presets)* to points in a three-dimensional geometrical representation, and control the sound models by interpolating values while navigating in this model. Other approaches include the creation of evolutionary algorithms that creates new generations of presets based on their "parents", or statistical models that learn relationships between multidimensional control parameters and sound parameters. These systems have in common that they do not require any specific knowledge about the parameters in the sound engine, because the performer interacts with the models and not directly with the sound parameters. As models can be designed to feature intuitive and musical interfaces, model-based mapping strategies carry the potential to become extremely important for future innovations in DMI development.

Mapping is, arguably, the most challenging research topic within the field of digital musical instruments. Regardless of how sophisticated the controllers and sound engines are, it is the chosen mapping strategy that affects the way the instrument will be played and its effectiveness. Experiments have demonstrated that simple, straightforward and obvious parameter mapping is less engaging, and therefore less rewarding, than mapping where a certain degree of effort is required to achieve an aesthetically pleasing sonic result (Hunt et al. 2003). The risk of losing control, it seems, is an important musical factor.

2.5 Communication Protocols: MIDI and OSC

Just as humans need language to communicate through speech, the mediation of digital information between different hardware components is dependent on *protocols*. A protocol is a set of rules that enables the connection, communication and data transfer between computing endpoints. Until the early 1980s, each synthesizer had its own unique control surface; devices from different manufacturers were not compatible with each other and could not be interconnected. In 1982, a group of instrument manufacturers joined forces to define a standard protocol that would allow communication between all digital instruments that adhered to the standard (IMA 1983). The result was MIDI (Musical Instruments Digital Interface), and the first instruments with built-in MIDI connections began appearing in 1983. The protocol and its associated standards revolutionized the music industry. Not only could one controller be used to control any number of synthesizers; MIDI standards were also gradually devised and developed to include extensive communication between controllers and computer-based music software, instrument maps for composition, notation and the exchange of musical arrangements, and time management tools for recording. As such, the impact of MIDI cannot be overstated. The great strength of MIDI is the fact that all official MIDI standards are continually developed and maintained jointly by two organizations—The MIDI Manufacturers Association (MMA) in the US and the Association of Musical Electronics Industry (AMEI) in Japan. This ensures compatibility among all MIDI products. Even today, MIDI is the de facto standard in the commercial music industry, and virtually all digital music devices are MIDI compatible. The protocol itself, however, is based on outdated technology and has a number of weaknesses that are generally acknowledged by musicians, researchers and manufacturers alike. Weaknesses include (Loy 1985; Moore 1988):

- *Low resolution*—7 bit data transfer, which means only 128 levels per parameter.
- *High latency*—delay in cables and interfaces (but not so much if MIDI messages are transferred through the USB protocol, which is increasingly normal).
- *Serial nature*—messages are sent and received one by one, not in parallel. For example, when triggering a note, the note number is transferred first, then the velocity, and so forth. This also adds to the inherent latency. Although usually not audible, it could be problematic for dense chord structures with high polyphony.
- *Discrete 12-note based system*—MIDI is founded on the keyboard paradigm, with its 12-note equal tempered scaling system. Hence, controllers based on continuous pitch ranges or with micro-intervals need to be implemented in this 12-note system by means of unwieldy adaptations.

Despite these weaknesses, the ubiquity of MIDI shows no signs of abating. The main reason for this is that no other protocols are anywhere near reaching an agreed standard, and so manufacturers must adhere to MIDI in order for their products to maintain profitability.

Among the several protocols that have been put forward to overcome the limitations of MIDI, Open Sound Control (OSC) currently holds the position of being the most popular, and a much more powerful, flexible and accurate, alternative. OSC is based on messaging with a URL-style symbolic naming scheme, and is intended for sharing control data in and between hardware devices and software (Wright and Freed 1997). Being an open standard, few limitations are forced upon the user. OSC is currently used extensively in experimental controllers developed in the research community, and a few commercial products[5] have also enabled OSC messaging. In contrast to MIDI, however, the protocol is not governed by any centralized organ, hindering the creation of standard namespaces that would enable efficient communication between any OSC-enabled devices. As it stands, mappings between OSC devices need to be defined by the individual users before they can communicate, and this is a great drawback in terms of cross-platform compatibility.

To summarize, MIDI can be viewed as the *lingua franca* of DMI control. Despite its limited and antique vocabulary, it will prevail as long as a viable, universal alternative fails to materialize. MIDI was created at an early stage in digital music performance. The community of instrument developers at that time was small enough to reach a consensus. Since then, however, the community has expanded exponentially, and is so diverse, that reaching a consensus for a new universal protocol seems far away.

2.6 Conclusion

DMIs are compounded systems consisting of several components that fulfill different functions within the system, and the communication between these. The short introduction to sensors, controllers, sound engines, mapping strategies and communication protocols offered in this chapter underscores the immensity of the field. Although there are few limitations, theoretically, to what kinds of sound that can be programmed, facilitating flexible and dynamic sound generation in real-time is a great challenge. Thus, developing innovative DMIs for real-time performance requires an acute awareness of all these areas of research.

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[5] E.g. controllers from Monome or JazzMutant *(*cf. *Lemur, p. 13)*, and, on the software side, Native Instruments *Reaktor* or Cycling '74 *Max/MSP/Jitter*

Chapter 3 – Embodied Music Cognition

In this chapter, we turn our attention from relatively explicable technology to a vastly more complex scientific topic: the acting and perceiving human body. The field of *embodied music cognition* studies the human body in its relation to musical activities, aligning itself with a relatively recent school of philosophers, psychologists and neuroscientists who maintain that our mental processing is inseparable from the body. The shift of perspective entails viewing music as experienced sound – an expansion to viewing music as physical sound (Leman 2007: 49). This perspective may be beneficial when designing DMIs. After all, music can be seen as the expression of human thoughts, feelings and values. The overriding guiding principle should be to create technology that advances such expression – not technology for its own sake.

3.1 Background

Embodied music cognition has roots in *ecological psychology*, a term whose origin is often attributed to the American psychologist James J. Gibson (1979). According to Gibson, our cognitive system should not be seen as something separate from the environment in which we act. We have evolved to perceive the world on a need basis; only those organisms that were able to interpret their environments correctly and behave accordingly have survived to reproduce (Cook 1999: 21). One of the consequences of this inheritance is that we automatically look for *affordances* in the external world. An affordance, another term coined by Gibson, is the potential function of an object we perceive. For example, when we look at a chair, we immediately recognize it as an object that *affords* sitting. We see the same affordance in benches, bar stools, and even objects in nature, such as rocks or tree stumps. In other words, what we immediately perceive in objects are values in terms of action.

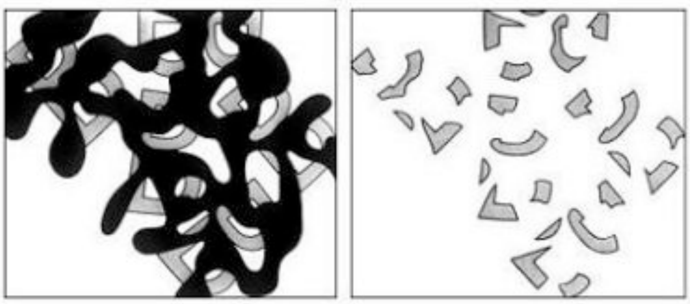
In the auditory domain, a fascinating aspect of ecological orientation is our ability to pick out sounds in the environment that are important to us. Because many naturally occurring sounds have fixed overtone structures, our auditory system has evolved to perceive sets of mathematically related frequencies as entities belonging to the same sound sources. This is especially true for sounds that contain a series of harmonics that are related to each other by whole-numbered ratios: they give rise to our perception of pitch. Thus, we can easily pick out individual voices, even in a room filled with many people having multiple conversations. Bregman (1990) refers to this ability to discriminate between different sound events as the *cocktail party effect*. It is not difficult to imagine why this ability has been important to our survival. It enables, for instance, a parent to pick out the sound of his or her child crying against the backdrop of a number of other loud noises. This is a remarkable feat; it is an area where human perception far exceeds the processing capacities of a computer. On the other hand, humans "filter out" much information that is not of immediate importance. As such, our representation of the environment is quite poor in terms of detail. We perceive in order to act, while a computer processes indiscriminately everything that its sensors are able to pick up.

The embodied approach may be seen as an extension to *phenomenology* and *Gestalt theory*, and an alternative to *cognitivist* and *connectionist* paradigms (Varela et al. 1991; Leman 2007). Academics within the phenomenological tradition have made a science out of the study of human subjective experience. Phenomenology as a discipline was developed the early 20th century by Edmund Husserl and further expanded by other influential philosophers such as Martin Heidegger and Maurice Merleau-Ponty. Despite relying mainly on methods of introspection, phenomenological approaches have nevertheless made an impact in fields not primarily concerned with philosophy, such as psychology and cognitive neuroscience. In music, the French composer Pierre Schaeffer made notable use of phenomenological tools when he observed that an objective description of music does not always correspond to our perception (Schaeffer 1966). Schaeffer's work is based on the derivations of this insight, and he introduced the concept *reduced listening*, which, briefly summarized, consists in suspending judgment about the natural causes of *sonorous objects* in order to examine the features of the sound itself (Godøy 2006). A sonorous object (or *sound object*) is a short stretch of sound perceived as an "intentional unit," represented in consciousness by the listener's own mental activity (Schaeffer 1966: 263). Schaefferian theory has significantly influenced the work of many electroacoustic composers and electronic musicians. He was also the first composer to create works consisting of solely recorded material, and is therefore regarded a pioneer in sampling.

Gestalt Grouping

Gestalt psychology has provided a rich basis for research within psychoacoustics (Cook 1999). Gestalt theory is well known for its use of various optical illusions to show that our cognitive system is geared toward grouping fragments of perceptual stimuli in order to identify discrete objects – even when sufficient stimuli are unavailable to our senses. Although the founders of the Gestalt school of psychology, most notably Max Wertheimer, primarily focused on examples from the domain of visual perception, auditory parallels can be found for all the classic Gestalt principles of grouping (Bregman 1990). Here, I shall briefly present some of these principles.

- *Closure*. We tend to “fill in the gaps” if an object is partly obscured. In figure 3.1a, we clearly perceive the gray fragments as belonging together to form the letters B. Figure 3.1b shows the same fragments without the mask. The forces of closure are stronger in 3.1a, because we are led to believe that there is evidence missing. In the auditory domain, the principle of closure has been proved to act in a similar way. For example, a long tone interrupted by burst of noise is perceived as continuing through the noise. This holds true even when the tone is completely removed while the noise lasts (ibid. 1990: 27).



Figures 3.1a, left, and 3.1b, right (Bregman 1990: 26–27).

- *Proximity*. Things that are located close together tend to be grouped as belonging to the same object. In music, we can hear the proximity effect in certain arrangements with fast passages of notes alternating between high and low pitches, for example in Bach’s Violin Partita (BWV 1004). The high and low pitches form separate groups of melody, giving a polyphonic effect even though only one note is played at a time (Cook 1999: 32 & 123–125).

Figure 3.2. Proximity (ibid. 32).

- *Similarity*. When objects are evenly distributed, we tend to group objects that appear similar in shape or size. The same can be said about auditory objects: similar timbres tend to belong together, and are grouped accordingly.

Figure 3.3. Similarity (ibid. 32).

- *Symmetry*. Objects that exhibit symmetry indicate that they belong together, and our brains tend to organize them just so. The extensive use of *retrograde melodies* in *counterpoint* is a case in point.

Figure 3.4. Symmetry (ibid. 32).

- *Good continuation*. Objects that are arranged in such a way that they seem to continue each other are likely to be grouped perceptually (ibid. 32). Smooth lines and curves are detected by our mind as belonging together. This is how a melody can take the foreground even in complex musical arrangements with similar instruments playing together.

Figure 3.5. Good continuation (ibid. 32).

- *Common fate*. Objects that move together are likely to be connected. The principle of common fate is much stronger than the other Gestalt principles (ibid. 33–34). The principle cannot be demonstrated in a static image. By photocopying Figure 3.6b onto a transparency sheet and moving it back and

> forth while superimposed on top on Figure 3.6a, the former image will “come alive” when in motion, and “disappear” when stationary. The effect is prevalent in nature. Animals that have evolved to blend in with their surroundings can be virtually impossible to see except when they are moving. The principle of common fate is the reason why a singer with a strong vibrato can be heard over the sound of a whole symphony orchestra. The timbre of the singer’s voice consists of the fundamental frequency and all of its partials. When the pitch goes up and down, all of the partials follow in a perfectly correlated manner, and thus the singer’s voice immediately stands out to a human perceiver.

Figure 3.6a. Some random dots, and 3.6b another set of dots. Superimposing 3.6b on top of 3.6a and moving it back and forth will make the superimposed image “come alive” even though the distribution of dots is completely random (ibid. 34–34).

At this point, it must also be mentioned that our perception is inherently *multimodal* in nature (Berthoz 1997). Not only do we group stimuli within one perceptual mode, as in the examples above. We are also experts at combining stimuli across modalities in order to attain the best possible perceptual image of objects and events in our environment. For instance, in a normal conversation, we *hear* a person’s voice, *see* the speaker’s facial expressions, gestures, posture and his or her lips moving, and (perhaps) *smell* the body odor. We rarely think about which modality is at work. The sensory organs and the brain work together in a concerted fashion in order to achieve a composite image of something that is the focus of our attention.

Gestalt principles of grouping are strong indicators that we have evolved to make sense of our surroundings based on statistics that have been virtually imprinted into our genetic code. Grouping occurs automatically and is an innate mechanism; it does not need to be learned (Cook 1999: 34). Because of this intricate perceptual machinery, in combination with several other innate and schema-based cognitive inclinations I have yet to mention, synthesized sounds are often fundamentally alien to human perception. Freed from the constraints of mechanical generation, digitally produced sounds do not necessarily trigger innate recognition patterns in our brain in the same way most acoustic sound sources do. Keeping this fact in mind may be important in the context of DMIs, and it is a point I will return to several times in this thesis.

Cognitivism and Connectionism

The paradigm of *cognitivism* gained stride in the 1950s, at a time when the discipline of computer science was in its developmental stages (Varela et al. 1991). This was also the decade when the computer scientist Max Mathews wrote MUSIC[6] (1957), the first widely used computer program for sound generation. The cognitivist view of intelligence as a rule-based system of information processing dominated the latter half of the 20th century. Central to this paradigm is the notion that cognition is the manipulation of symbolic representations after the fashion of digital computers. The idea of viewing the brain/body as *hardware* and mental representations as *software* is a typical example of this perspective. Thus, the Cartesian division between mind and matter is upheld. The impact of this paradigm is evident in the way much music software and sound synthesis techniques have been developed. Rule-based systems are highly precise and accurate within the limits of operation. However, high precision and accuracy are not always desirable aspects in music, as will be argued later in this chapter. Furthermore, such systems often fail to account for structures that fall outside of the rules being used in the model (Jensenius 2007: 14).

Cognitivism was challenged early on by an alternative orientation in cognitive science, namely *connectionism*. In this paradigm, the main source of metaphors and

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[6] http://en.wikipedia.org/wiki/MUSIC-N

ideas is the brain itself (Varela et al. 1991). Whereas cognitivism lends concepts from digital computing, connectionism presents the view of cognition as a distributed system of interconnected *nodes* (or neurons), as with the brain. The strength of the connections (the *weights*) between the nodes provides the basis for learning in such a system (Jensenius 2007: 14). The weights increase upon repeated use and a network of parallel processing algorithms is gradually formed. Although connectionism was promoted as an alternative virtually at the same time as the cognitivist approach grew popular, it was only in the late 1970s that connectionist models gained wide acceptance (Varela et al. 1991). Because these models are more similar to the processing capabilities of the brain, they are better at finding relationships between data, and at providing relative answers. In other words, such a system is not dependent on explicit mapping strategies between input and output data (Jensenius 2007: 14). Such systems may produce more interesting, but less predictable, musical results.

Both the cognitivist and connectionist paradigms have received criticism for neglecting the subject's involvement with the environment (Leman 2007). The ecological approach posits that knowledge does not emerge from passive perception, but from the need to act in an environment. This action component is the vantage point for the embodied approach.

3.2 Perception and Action—Two Sides of the Same Coin

If we are to take the ecological perspective at face value, we must assume that there is an action component in the perception of music. Furthermore, we run into an important question when considering the function of music. An average person spends a considerable amount of resources to gain musical experiences: through listening to music on portable players, at home, while working out, at concerts and night clubs, or, perhaps, by learning to play an instrument, playing in ensembles, or composing. As far as we know, music in some form or other has been a part of every human culture throughout history (Mithen 2005). What can explain this drive to experience music? If, indeed, we perceive in order to act in our environment in a way that is beneficial to our survival, then music must be quite important, considering its ubiquity. Leman

(2007) proposes that people get involved with music in order to experience *behavioral resonance* with physical energy. I propose an extension to this claim by lending a concept from the French composer Edgar Varèse (admittedly out of context), who is often cited for his definition of his own music as "organized sound." Perhaps people get involved with music in order to experience behavioral resonance with *organized* physical energy. My aim here is to strengthen the (human) action component and the socio-communicative aspect: music is sound (and other types of physical energy) filtered through the actions of an organism. The etymology of the words "organize" and "organism" provides an interesting insight. They both originate in the Greek word "organon," which can be translated as "implement, musical instrument, organ of the body," or literally "*that with which one works*."[7] This ties in neatly with the embodied approach to musicology. The feeling of behavioral resonance with organized physical energy attained through music may be beneficial for self-identity, interpersonal relationships, mood and mental order, all of which can contribute to a better understanding of ourselves in the world.

The embodied approach takes the ecological view of the relationship between perception and action a step further by claiming that sensory and motor processes are fundamentally inseparable in lived cognition.

> In a nutshell, the enactive approach consists of two points: (1) perception consists in perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided (Varela et al. 1991: 173).

In other words, mental representations are built upon action representations. The far-reaching consequence of this claim is that we cannot have a mind without a "database" of experienced actions—the database being the entire body including the brain. There is no such thing as a disembodied mind. This rejection of dualism should by no means be considered philosophical pandering. Cognitive neuroscientists have disproved the existence of any center in the brain that could be considered a link between the "outer" physical world and the "inner" world of mental representations.

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[7] http://www.etymonline.com/index.php?term=organ

Damasio (1999) proposes that the feeling of self and the sense of having a mind emerge as the brain monitors its own actions in relation to the physical environment.

Evidence for perception–action coupling

The hypothesis of neural couplings between perception and action is not new. In the field of linguistics, the *motor theory of speech perception* has been around for several decades (Liberman and Mattingly 1985). This theory states that phonetic units, the building blocks of language, are perceived by recognizing *articulatory gestures* that could have caused the sound, rather than through a pure auditory analysis of the sound itself. Ever since its first formulations in the 1950s, the motor theory of speech perception has been a target for criticism from a number of scientific fields. For example, it has been pointed out that people born with severe defects in speech production are nonetheless capable of developing normal levels of speech perception (MacNeilage et al. 1967). Until relatively recently, motor theorists have generally been in defense mode, countering their critics by specifying or modifying their initial claims. Controversies aside, the discovery of *mirror neurons* and subsequent studies have revived the motor theory of speech perception, and motor theories of perception in general. Mirror neurons were first described by Gallese et al. (1996) after discovering that a particular set of neurons in the brain of a monkey were activated both when performing a goal-directed action, and when observing the same action performed by an experimenter or another monkey. The neural patterns that are activated in perception mode are not identical to the ones activated in action mode. However, the degree of overlap is enough to support the notion of perception–action coupling. Mirror neurons produce covert action *representations*. These representations may serve a number of different functions, such as motor learning and the understanding of meaning of the observed action (ibid. 606). Spurred by these experiments, Rizzolatti and Arbib (1998) conducted a series of studies on humans. Using PET[8] brain scanning techniques, they showed that motor areas of the brain were activated during speech perception. Many other studies in the past decade have provided compelling evidence supporting perception–action coupling. In short, evidence seems to support the hypothesis that motor activity as represented neurally forms a link between the mental and physical worlds.

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[8] Positron Emission Tomography.

Wilson and Knoblich (2005) suggest that action representations may have both *postdictive* and *predictive* functionality: they may help us both in understanding the cause of, or the motivation behind, the perceived action of another person, and in projecting possible future trajectories of the action in order to adjust our behavior accordingly. The ability of simulating actions, it seems, is a fundamental aspect of humans as social beings. It is a skill developed throughout life, starting out as pure imitation in very young infants (Jeannerod 2005). As one grows older, imitative behavior becomes progressively inhibited, giving way to an increasing degree of empathy achieved through covert simulation of other people's actions. This development entails the inclusion of progressively higher brain structures as empathizing with other people's feelings and attuning to their thoughts involve increasing degrees of abstraction and symbolic representation. However, motor areas of the brain seem to hold the key. Awareness of the state of another person's body is dependent on the awareness of our own body, and higher cortical levels query lower levels in a reverse hierarchical fashion in order to obtain this awareness (Adolphs 2005: 21).

In the beginning of this section, I introduced the concept of behavioral resonance. Clearly, the process of attuning to and empathizing with other people as described above could be seen as a case of mutual behavioral resonance. The feeling of behavioral resonance with organized physical energy in musical experiences could be seen as related to interpersonal behavioral resonance, especially in the setting of live music performance. Leman (2007) suggests that music can be seen as a virtual social agent whose actions can be emulated. Our intrinsic drive to understand the cause of what we perceive leads us to perceive actions in music. Or rather, I believe we perceive *effort*. In many acoustic instruments, physical effort is particularly perceivable. We can hear the performer's breath in wind instruments, the kinesthetic maneuverings of percussionist, and so on. Thus, it can be said that music performed on most acoustic instruments affords behavioral resonance on a sensorimotor level of perception–action. Due to the separation between controllers and sound engines, such an affordance is not necessarily available in DMIs—it depends on the choice of sensors, the type of actions needed to use the controller, and the mapping to the sound engine. Also, it demands more schema-based knowledge on the part of the audience, because understanding the cause of the sound is based on inference. Therefore, behavioral resonance may be more easily achieved on an abstract, conceptual level when performing on DMIs. Along with a growing number of musicologists (Godøy 2003; Aksnes 2003), I suspect that the activation of sensorimotor brain circuits may be important to many people's experience of music, because the motivation behind perceiving physical action is innate, and the sound more directly perceived. I share the belief that sensorimotor approaches may prove to be a fruitful area of research.

3.3 Memory

In figure 3.7, Snyder's (2001) diagram demonstrates how the human cognitive system deals with different types of memory when receiving musical stimuli. This memory model is meant to portray processes, rather than different places in the brain. The diagram shows a perceptual/cognitive process starting at the bottom, where auditory stimuli enter the ears, and ending at the top, where the perceived auditory events enter the focus of conscious awareness. Along the way, there are several stages of processing: **(1)** Continuous, raw information carried by thousands of nerve impulses from the inner ear persists briefly as echoic memory (on the time scale of less than a second), which is just enough time needed for **(2)** feature extraction/perceptual binding. At this level, largely innate mechanisms detect various features of the continuous auditory stream, such as pitch, overtone structures, pitch contours, simultaneous intervals and loudness changes. Different features are unconsciously grouped to form coherent events (some aspects of this process is described in the section about Gestalt grouping in Chapter 3.1). After the binding process, the information is no longer continuous, although some of the continuous acoustic features may enter conscious awareness directly (ibid. 7).

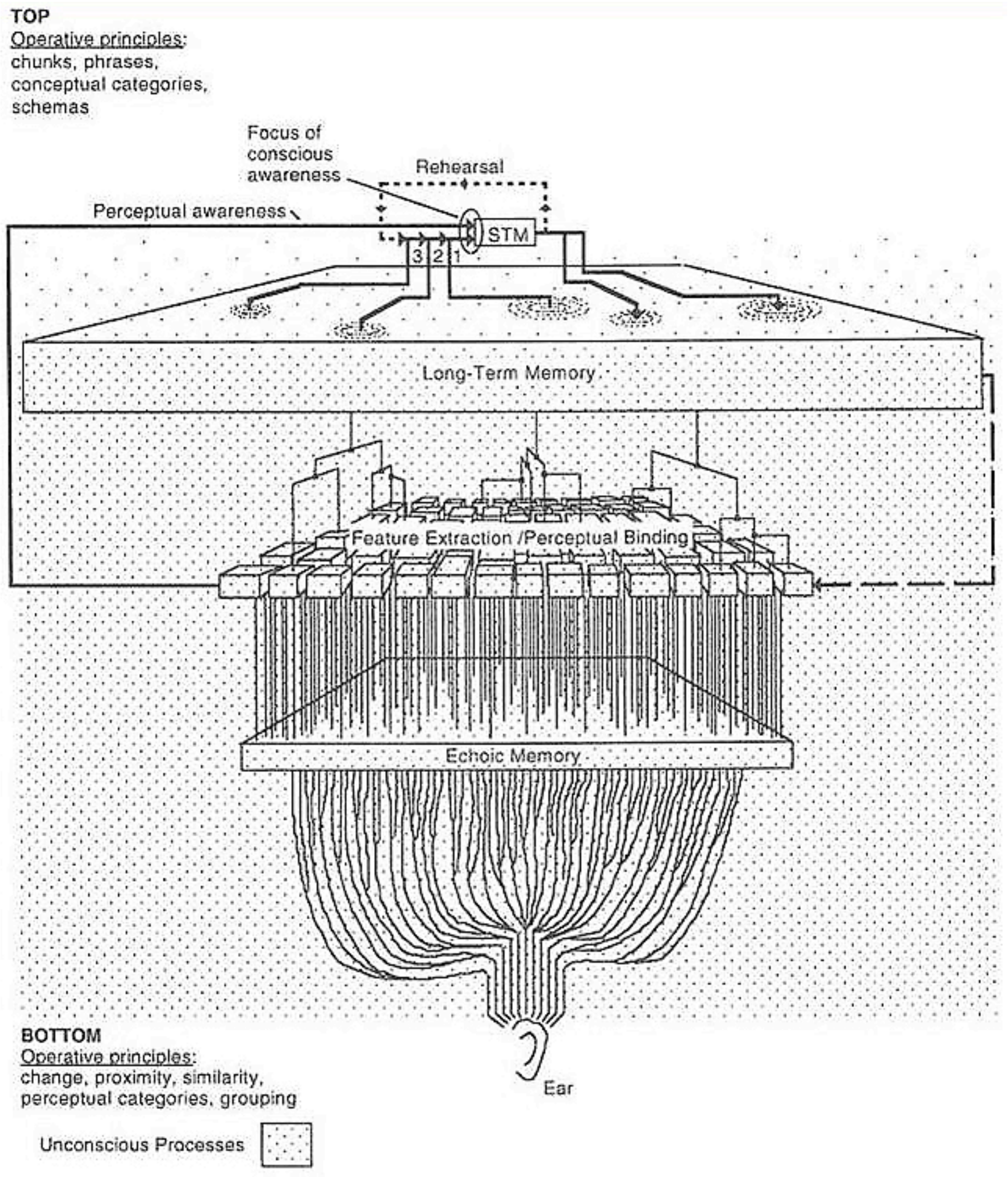

Figure 3.7. Memory diagram (ibid. 6).

This is illustrated with the thick line connecting the level of feature extraction/perceptual binding directly with conscious awareness. **(3)** Perceptual categories are filtered through long-term memory (LTM), activating conceptual categories, which are much larger networks of memories, constituting knowledge about the perceptual categories that activate them (ibid. 8). At this point, the dots symbolizing unconscious processes decrease in density, which is meant to show that some content of LTM may become semi-activated in consciousness, and may have a large effect in guiding what becomes fully activated. **(4)** Conceptual categories that are fully activated enter the focus of conscious awareness, in parallel with uncategorized perceptual awareness and information fed back from **(5)** short-term memory (STM). STM lasts 3–5 seconds on average, and consists of activated categorized memories. We can normally hold no more than a few (less than 10) *different* elements active in STM at a time. The content of STM can be rehearsed, which means that events of particular interest can be kept activated by recalling them from STM back into the focus of conscious awareness. If such an event is rehearsed repeatedly, the chance increases that it will "stick" in LTM.

I emphasize that there are no locations in the brain dedicated to these memory modes and categorization processes. The diagram describes *processes*. However, I find that the model has a great deal of explanatory power—it gives a good, albeit simplified, overview of how the human cognitive system perceives sound. In the context of the upcoming section in this chapter, I find it particularly interesting to consider the transient nature of perceptual information entering conscious awareness directly from echoic memory. The information is lost the moment it exits the focus of conscious awareness, because it bypasses the function of LTM. Snyder refers to this information as *nuance*. Because the experience of nuances takes place outside categorical structure of LTM, it is difficult to describe verbally. Yet, when listening to music, nuances contribute to the subtle ongoing "feel" of the music, and often carry important emotional information (ibid. 86).

3.4 Emotions, Metaphors and Vitality Affects

Most people seem to agree that emotion is an important factor in musical experiences. However, there is no consensus across disciplines on what the term emotion implies. Even the field of affective science seems to be divided in their views on whether emotions are purely sets of somatic reactions to stimuli (Damasio 1994; 1999), or cognitive evaluations of the readouts of the brain's registration of bodily conditions and changes (Ortony et al. 2005). The former views emotion as outputs from the brain, while the latter defines emotion as the interpretation and appraisal of inputs to the brain. Sloboda and Juslin (2001) suggest that much of the confusion and controversy may revolve around *semantics* rather than *function*. Regardless of definitions and academic approaches, it seems that most researchers agree upon the regulatory role of emotions in human behavior—the phenomenon tends to lead to expressive, goal-directed and adaptive actions (Kleinginna and Kleinginna 1981: 355). Purely for semantic reasons, I prefer the somatic definition, because it appeals to me that emotion (cf. the etymology of "emotion", from Latin: *move out*) should be about physiological activity and not about cognition. However, this does not necessarily mean that I disagree with alternative views—I am, for practical reasons, settling on a choice of words. Table 3.1 presents a schematic, simplified version of two of the more contrasted definitions of the term emotion.

Stimulus	**Reaction**	**Feeling**	**Emotion**
A perceived object or event in the environment or recalled from memory	A set of chemical and neural responses to the value of the stimulus, resulting in an altered body state	Readout of the brain's registration of the altered body state	Cognitive evaluation of the brain's registration of the altered body state
Stimulus	**Emotion**	**Feeling of an emotion**	**Knowing the feeling of an emotion**

Table 3.1. The cognitive (top) versus the somatic (bottom) view of emotion, as interpreted by myself. The chain of events should be seen as going from left to right. I emphasize that this representation is simplified—the intention is to demonstrate how different definitions of the term emotion may be preventing an interdisciplinary focus on the physiological and cognitive events involved in emotional experiences (i.e. the entire chain of events from stimulus to cognitive appraisal of the body's reaction to the stimulus).

In music philosophy, there has been much debate between the so-called *cognitivist* and *emotivist* views of emotion in music (Kivy 1990). The cognitivist position holds that music simply expresses emotions without inducing them, whereas the emotivist position holds that music elicits emotional responses in listeners. I agree with Aksnes (2003) that these positions are not necessarily mutually exclusive. In interpersonal communication, the degree to which one actually feels what another person is feeling depends on the degree of empathic involvement. According to the embodied perspective, empathy relies on simulation of the other person's actions. In other words, recognition must necessarily precede emotional alignment. As mentioned earlier, music can be seen as a virtual social agent, and I believe that the degree to which music can elicit emotions is highly dependent on the empathic involvement of the person having the musical experience.

Most research on emotions in music has been based on so-called *categorical* or *dimensional* approaches (Sloboda and Juslin 2001), or a combination of these approaches. The categorical approach identifies a set of *basic* emotions, such as happiness, anger, sadness, fear and disgust.[9] Basic emotions are regarded as innate and universal categories from which all other emotional states can be derived. *Secondary* emotions, which are seen as more complex combinations of basic emotions, are prone to cultural variance due to developmental influence. In the dimensional approach, emotions are identified based on their placement on a small number of dimensions, such as *valence* and *activity* (ibid. 77). In his research on the communication of emotion in music performance, Juslin (2001) combines the categorical and dimensional approaches to demonstrate how groups of various *expressive cues* may give associations to certain emotions in the listener.

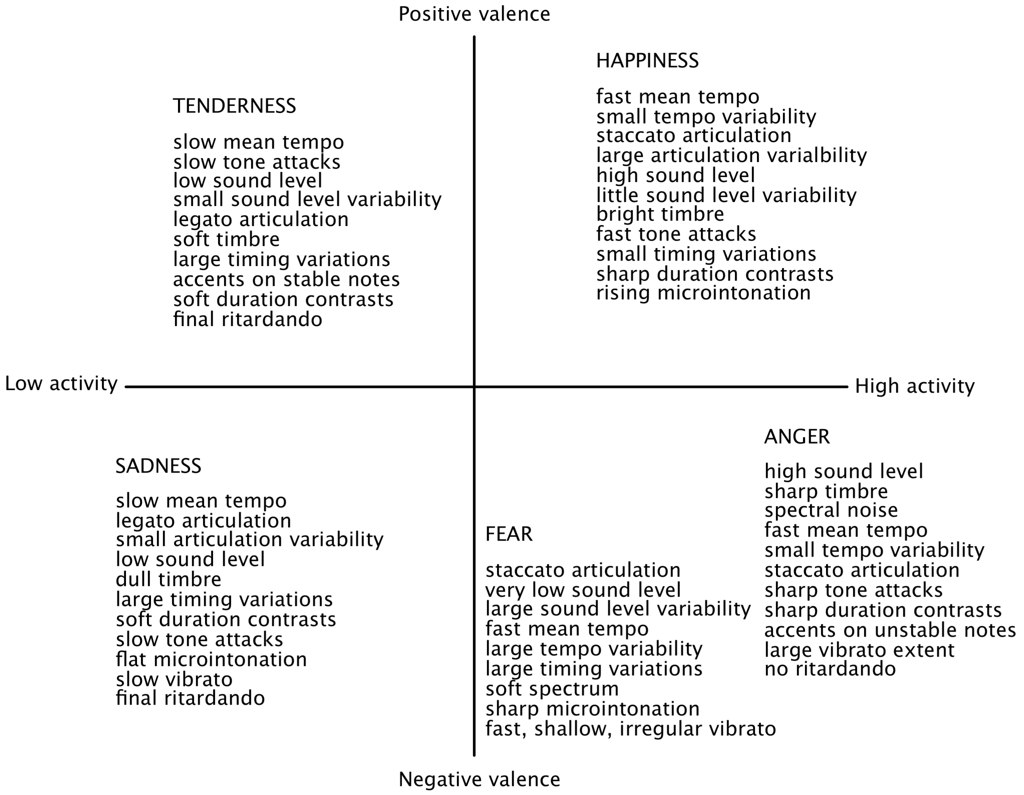

Figure 3.8. Grouping of expressive cues in music performance, and their associated emotion categories represented in a dimensional model (ibid. 315).

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[9] The number of emotion categories defined as basic varies among different researchers. However, there is a high degree of consensus that these five emotions should be considered basic.

Juslin's model, which is based on years of research conducted by himself and several of his colleagues within the community of affective science, provides an interesting overview of performance-related features that communicate easily identifiable emotion categories. However, it does not give us any account of *how* these expressive cues are translated into representations of emotion in the listener. A possible answer to this question is provided by the *cognitive metaphor theory*, also known as the Lakoff-Johnson theory (Lakoff and Johnson 1980). According to this theory, a basic property of human cognition is the ability to understand one conceptual domain in terms of another. This is referred to as *metaphorical projection*, and the directionality of the projection tends to go from concrete and physical concepts to more abstract concepts. When saying, for instance, that "a melody is a path", we are projecting the concept of a physical path onto the more abstract concept of a melody (Snyder 2001: 108). According to Lakoff and Johnson (1980), all cognition relies on many layers of metaphorical projections, with roots all the way down to sensorimotor experiences. The embodied approach described earlier is essentially based on the idea of cognition as a hierarchical structure of metaphorical projections. In regards to Juslin's research on the relationship between expressive cues in music performance and the recognition of emotion in musical experience, we can see how cognitive metaphor theory may provide an explanation. The listener may project auditory features of the music onto memories of the kinesthetic and visceral aspects of an emotional experience, resulting in a relay of further projections which may end up in the recognition of an emotion.

I find cognitive metaphor theory appealing in the context of this thesis, because the chain of events in metaphorical projection bears resemblance to the flow of information in digital musical instruments. Lakoff's definition of metaphor as "a cross-domain mapping in the conceptual system" (Lakoff 1993: 203) is a case in point. The mapping of control parameters onto sound parameters is basically a projection of information between two separate domains[10]: the control *(source)* domain and the sound *(target)* domain. In order to convey basic emotion categories effectively with DMIs (if this is deemed important for the music), a strict correlation between the actions of the performer and the sounds generated in the sound engine may be necessary. According to the theories presented in this chapter, the innate and

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[10] Here, I am projecting the concept of DMIs onto the concept of metaphorical projection.

universal features of basic emotions are immediately recognized, also when projected as sound onto long-term memory structures. Although basic emotions in all likelihood may be inferred from sounds generated as a result of more arbitrary or experimental mapping strategies, I do not think the recognition of basic emotions would be as direct and strong. In such cases, it seems to me that top-down, schema-based cognitive processes would need to be involved to appreciate the auditory stimuli, resulting in a more analytical mode of musical experience.

Most of the time, I think music expresses affect in a much more complex and subtle manner than in the form of discrete categories of emotion. In the previous section about memory, we learned that auditory events that are not grouped and categorized via the structure of long-term memory may be experienced momentarily as raw, continuous perceptual information. As mentioned in the previous section, Snyder (2005) refers to this as *nuance*. In order to understand the importance of nuance in music performance, I find the developmental psychologist Daniel Stern's (1985) notion of *vitality affects* particularly useful. Stern defines vitality affects as dynamic, kinetic qualities of feeling that correspond to the momentary changes in feeling states involved in the organic process of being alive (ibid. 156). Whereas categorical emotions are experienced intermittently, vitality affects are constant, dynamic shifts or patterned changes which occur both in the presence of and in the absence of categorical affects.

> These elusive qualities are better captured by dynamic, kinetic terms, such as "surging", "fading away", "fleeting", "explosive", "crescendo", "decrescendo", "bursting", "drawn out", and so on (ibid. 54).

Stern emphasizes that vitality affects are *amodal* in nature, which means that they are not tied to any specific categories of emotion. For example, someone getting out of a chair "explosively" can be caused by many different emotions, such as anger, surprise, joy or fright—or by no particular emotion at all. "Vitality affects concern *how* a behavior, *any* behavior, *all* behavior is performed, not *what* behavior is performed." (ibid. 157) Sloboda and Juslin (2001) suggest that researchers may be thinking about something akin to vitality affects when they speak about affect in music, rather than true emotions. Via references to the philosopher Suzanne Langer, Stern himself provides several examples of the potency of vitality affects in music and art, claiming that artistic style could be considered the counterpart to vitality affects in spontaneous behavior (Stern 1985: 159). I interpret “artistic style” in this context to be the same as what Snyder (2005) refers to as nuance. More recently, Hallgjerd Aksnes (2003) discusses vitality affects that contribute to the expressivity of a piece by the Norwegian composer Geirr Tveitt. She expresses the conviction that mappings between dynamic patterns in the music and similar patterns in our visceral experience are at least partly responsible for the expressivity of these elements (ibid. 275).

This leads us back to the notion of metaphorical projection. I share Aksnes’ belief that there is a fundamental correlation between musical nuance and the ongoing subtle, dynamic variations in feeling while experiencing music. Furthermore, I am convinced that these topics are of importance in the discussion of DMIs, because most synthesis techniques generate perfect periodic signals that fail to convey the performer’s imperfect performance. I think that many vitality affects may be lost in the mapping between action and sound, unless the instrument is designed in a way that captures different micro variations, and map these to sounds which in turn can function as targets for metaphorical projections by the person experiencing the music.

3.5 Conclusion

This chapter has taken an embodied approach to music cognition as its point of departure. Our perception and cognition are adapted to the environment in which we act, and through a review of various fundamental properties of our cognitive system, I have demonstrated the potential significance of sensorimotor representations in music. I have argued that increased knowledge in this field of research may improve mappings between controller and sound engine in DMIs.

Chapter 4 – Cultural Resonances

The ecological perspective presented in the previous chapter demonstrates that our perceptual and cognitive systems may be the result of an adaptation process, and the need to act in the environment in order to survive may be seen as the driving force behind this adaptation process. Most people would probably agree that the influence goes both ways—we also shape our environment according to our worldviews. This is evident, for instance, in the architecture and infrastructure that surrounds us. The integrated pattern of human knowledge, beliefs, values, social forms and behavior in a given environment is referred to as *culture*, as opposed to *nature*. Leman (2007) describes the interplay between natural/biological and cultural forces of influence as a resonance system in which our understanding of the world and our ability to act accordingly is constantly challenged. In this chapter, I will look at how our view of music undergoes change as a result of technological advances, and argue that aspects of our musical culture at the moment may be out of phase with the rapid technological development.

4.1 Natural and Cultural Constraints

In chapter 3, we were introduced to the term *affordance*. Gibson (1979) defined affordances as “action possibilities”. This definition implies that we seek out opportunities to act amidst a constant sea of limitations. The limits imposed upon us as acting organisms may be referred to as constraints (Leman 2007). Natural constraints subsume the laws of physics and biology, and form the study domain of the natural sciences. In addition to natural constraints, human action is also guided by what is acceptable, appreciated, and considered to be true or valid in a culture (ibid. 55). These rules, or domains of knowledge, can be referred to as cultural constraints, and underlie the study of human sciences. Historically, music has assumed an ambiguous position in between natural and human sciences. For example, music was taught as one of the four disciplines in the *quadrivium* (arithmetic, geometry, music and astronomy) in European mediaeval universities, as opposed to the three disciplines in the *trivium* (grammar, logic and rhetoric) (Kjerschow 1993). Over the course of the past few centuries, music as a discipline has drifted toward being regarded as one belonging under the umbrella of human sciences. However, the development of musical instruments, and the ongoing development of music technology, demonstrates the interdisciplinary nature of music.

Both natural and cultural constraints exert influence on the development of musical instruments (Leman 2007). Natural constraints include the availability of materials in the environment, tools (technology) with which instruments can be constructed, and the physiological and cognitive capacity of human performers. Cultural constraints may be the type of timbres, musical scales, rhythm structures, musical styles and musical habits preferred by a particular culture. Natural and cultural constraints interact continuingly in a complex manner, making it difficult to account for the diversity of musical cultures around the world. What is clear, however, is that the musical instruments of a particular culture, and how they are used, often reflect the musical preferences of the same culture. For example, most instruments in Western culture are constructed in such ways that harmonic resonances dominate over inharmonic resonances, which may be seen as reflecting the preference in Western culture for harmonic sounds in music. Other cultures, such as the Indonesian culture, seemingly prefer instruments that produce inharmonic structures (Sethares 1998). The question of why different cultures develop different musical preferences is not an easy one to answer. Leman (2007) suggests that cultures develop in resonance with particular natural constraints. Cultural constraints emerge when trends based on natural constraints solidify into cultural paradigms, and appear to be detached from their original natural environment. The *tritone* interval in music is a case in point. Due to the physiology of our inner ear and auditory cortex, the tritone is the interval where the number of frequencies competing within the same *critical bandwidths* is the highest, which causes a high degree of perceived *roughness* (Rossing et al. 2002). In medieval European church music, roughness (dissonance) became something to be avoided, because music was supposed to have a serene character in order to serve the function of worship. Perhaps because of its particularly restless character, the tritone was labeled “the devil in music” *(diabolus in musica)*. The “forbidden” tritone was a cultural constraint in Christian music for centuries.

A full-blown introduction to theories about how resonances between musical preferences and musical instruments of different cultures may have originated is beyond the scope of this thesis. Here, I will limit myself to highlighting the importance of technological advances in the development of musical cultures. Historically, new technologies have created new musical affordances. New affordances may appear in the wake of particular natural constraints that have ceased to exist. For example, the emergence of pipe organs that could be played with keyboards *(manuals)* afforded polyphonic performance by one person on a level hitherto impossible, due to the natural constraints of instrument design and human physiology. However, the appearance of new affordances are not necessarily recognized by a culture, because cultural constraints that have developed in resonance with natural constraints may have become so pronounced that a potential new affordance starts out as a “no-go area”. An example is the minimization of amplitude distortion for several decades after the invention of electronically amplified instruments. Distortion was simply not deemed musical. Rock and electronic music gradually changed this view, to the effect that many musicians now view distortion effects as things which offer, among other things, particularly powerful expressions of affect. Ogburn (1957) coined the term *cultural lag* to describe the notion that culture takes time to catch up with technological innovations. I think such lags between technological advances and cultural constraints may be seen as brief periods where cultural constraints are out of phase with natural constraints, in a relationship otherwise characterized by resonance. In such contexts, so-called experimental or avant-garde musicians play an important role in investigating potential affordances in new technologies. The experimenting may be seen as an orientation toward new media, where the goal is to find ways of expressing oneself truthfully and with relevance in an ever-changing environment.

In a parallel process, but on a completely different time scale, organisms adapt to their environments, as described in Chapter 3. I find the comparison between evolution in nature and development in culture interesting, because in many ways, the two processes may be regarded as mirror processes. Figure 4.1 shows a diagram demonstrating these mirror processes. In my visualization, technological inventions have a function in the development of the arts (including music) similar to the function of biological mutations in the evolution of life. The concepts of natural and cultural constraints are represented here as forces of influence upon biological and technological processes. The main reason behind representing the processes in this way is to demonstrate that biological mutations and technological inventions can create new affordances which may take time to be discovered—the creation of affordances is not necessarily planned. In the case of evolution, the time scale for adaptation may be thousands or even millions of years, whereas the time scale for orientation toward new media in the arts may be years or decades.

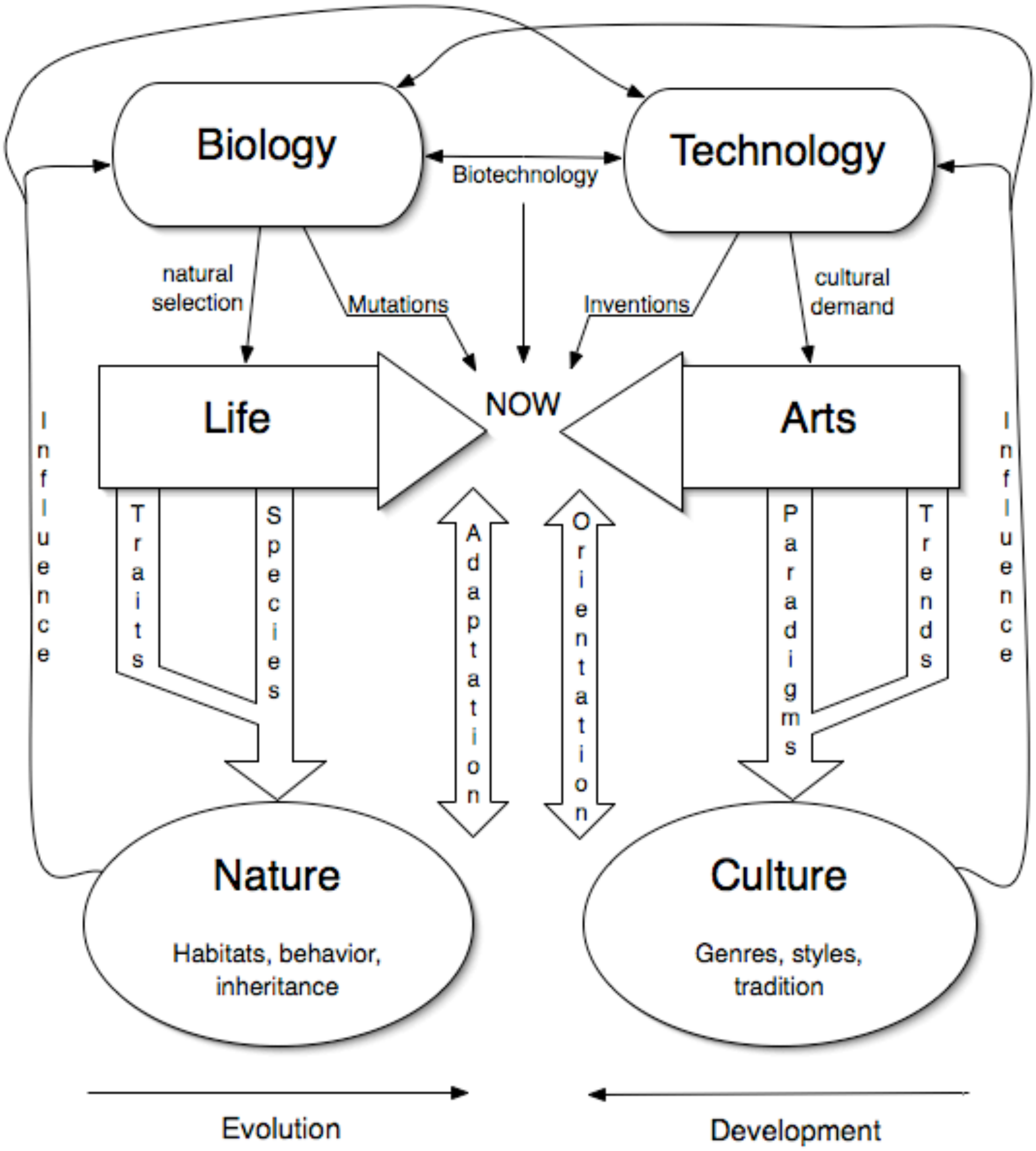

Figure 4.1. A diagram demonstrating the mirror processes of evolution of life and development of the arts. The diagram is my own representation of natural and cultural forces of influence upon biological and technological processes, resulting in the evolution of life and the development of culture.

In the case of digital technology, the amount of new musical affordances may be larger than most people realize. A great number of natural constraints have simultaneously ceased to exist, but many of the cultural constraints that have developed in "resonance" with these natural constraints are, for the time being, held in place. For example, the concept of music as composed and performed by humans is being challenged by the existence of virtual composing environments, where the software can be seen as composed by a person, but the music itself is not (Jordà 2005). Before the age of digital computing, it was less common to think of music as something that could materialize without being composed and/or performed by people. However, even now that computers afford music composed and performed by machines, it seems that many people are not willing to accept this as "real" music. The fact that the composed software may be seen a form of human artistic expression may not make a difference to many people.

Other natural constraints that have disappeared as a result of digital computing have to do with the physiological limits to the amount of individual sounds a performer can make with the instrument. In DMIs, there are virtually no limits. In many cases, an audience without any working experience with DMIs has no chance of detecting the virtuosity of a DMI performer, because virtuosity does not necessarily lie in the sequencing of notes or in dynamic/timbral fluctuations. In fact, the audience cannot know anything about the performance for certain, or even if it is a performance at all—it could all be preprogrammed. In order to relate to a live DMI performance, I think that the audience must either know the program that the instrument is running, understand how the program works, recognize at least some of the algorithms or functions used in the program, or witness consistent relations between the performer's actions and the sounds coming from the instrument. Hence, the concept of virtuosity faces challenge, and the DMI performer often assumes an enigmatic role in the minds of the population at large. I believe that traditional views of music and the lack of education about the musical possibilities offered by digital computing may be feeding back into cultural constraints, leading to the excessive development of DMIs oriented toward existing genres, styles and traditions instead of instruments pointing toward potential future areas of application.

4.2 Orders of Action–Sound Separation

In an essay entitled *Mechanical Music*, Bartók (1976) establishes a continuum ranging from musical instruments that he regards as being more *human* towards more *mechanical* instruments, according to the number of foreign objects that interfere between the human body and the vibrating sound source, and the amount of time the human body has control of the vibration. Based on these criteria, he places various instruments in the following order: the voice, wind instruments, bowed string instruments, plucked string instruments, pianos, organs, barrel organs, player pianos, and finally the gramophone and the radio (Jordà 2005: 24). Written in 1937, the essay provides an insight into the mind of an influential 20th century composer, and his concerns about what he calls the “mechanization” of music. He is generally biased against contemporary “optimists” who seem to believe that “mechanized” instruments (such as the theremin) could some day become a substitute for “live music.” He expresses fears about mechanical music flooding the world to the detriment of live music, and concludes: “May God protect our offspring from this plague!” (Bartók 1976: 298)

Whether or not we have been spared from this abominable fate may be an interesting discussion. Much has changed since Bartók’s essay. Although the vantage point of this thesis shows that DMI developers face similar challenges as the creators of “mechanical instruments” seven decades ago, I do not share Bartók’s pessimism. The separation between action and sound in DMIs is of different order than in the analog electronic instruments described in *Mechanical Music*. Similarly, the separation between action and sound in pianos is of a different order than in more direct acoustic instruments, and so on. Historically, I think that new, unique ways of experiencing and thinking about music have developed for each new order of action–sound separation that has emerged. The action–sound separation is paralleled with a need to act and perceive on new and different levels, resulting in new musical paradigms that are relevant for existing and future generations. I have identified five different orders of separation: *incorporated, direct, mechanical, analog electronic* and *digital*. I hasten to add, however, that the acoustic (pre-electric) orders should be seen as a continuum and not discrete categories.

Incorporated: The performer *is* the sound

While the voice is clearly the most versatile example in this category, whistling, snapping, clapping and various other percussive body sounds can be considered to be incorporated instruments. The earliest forms of music probably originated from body sounds, and may have been important for displaying commitment, strengthening social relations, communicating affect and producing different feelings of affect in others (Mithen 2005).

Direct: The performer is in direct contact with the sounding unit(s)

Most acoustic instruments could be classified as being direct, although to varying degrees. The Jew's harp borders against the incorporated category, because most of the sound is actually caused by the teeth and skull vibrating and resonating in the mouth and nasal cavities. Sound from wind instruments is also a combination of corporeal and instrument vibrations, but here the resonator is in the instrument. Toward the other end of the continuum within this category we have stringed instruments plucked with picks and percussion using sticks and mallets. Musical instruments that were separate from the body may have been what enabled the study of music as a science, exemplified by Pythagoras' musical theories and experiments with musical sound in ancient Greece. Additionally, the diversity of musical styles and practices around the world may be due to the materials used to make instruments—different timbres in combination with the human voice may have made some intervals sound better than others, thus creating characteristic musical scales dependent on a culture's natural environment (Sethares 1998).

Mechanical: The performer initiates mechanical processes that result in the production and (in some cases) modification of sound

Keyboard instruments, such as the organ, harpsichord and piano, and other instruments that have mechanical links, belong to this category. On this order of separation, action and sound can clearly be identified as different processes.

The increased range of control afforded by mechanical processes made it easier for one person to play polyphonic melody structures over several octaves, and may have elevated the role of the composer as an autonomous creator of music. The level of abstraction and conceptualization in composed works increased dramatically between the 16th and 20th centuries, and I think this development would have been impossible if many composers had not had the experience of developing and trying out themes and ideas on organs, harpsichords or pianos.

Analog electronic: The performer triggers electric impulses that are relayed to a sound generator

Early analog electronic instruments included the theremin, Ondes Martenot, Trautonium, and Hammond organs. Later, analog synthesizers became popular starting in the 1950s. Electronic instruments introduced sounds never heard in music before, and have greatly influenced the development of music culture in past decades.

Digital: The performer triggers streams of digital data which are coded into digital representations of sound and converted to physical sound

Already described at length in Chapter 2, this category features instruments with the highest order of action–sound separation to date. Digital music has existed for several decades, but the possibility of processing complex synthesis techniques and musical structures in real-time is relatively new (computers were not fast enough until the last decade). In other words, natural constraints prevented the real-time performance of digital music in the first few decades of its development, and musical styles based on preprogrammed sequences of sound have had more time to develop. I would not go so far as calling this condition a cultural constraint, but I think it forms a cultural context in which it may be difficult to realize how DMIs for real-time performance should be developed, because there is already a large demand for DMIs based on sequencing and with fixed mapping presets.

These five categories based on orders of action–sound separation form the basis for the empirical study in Part II. The musicians that I have interviewed are all DMI performers with the additional experience of playing non-DMI instruments. I have made sure that each one of the four categories apart from digital—incorporated, direct, mechanical and analog electronic—are represented by at least one of the participants. This selection of participants was based on a hypothesis that experience from different instrument categories may cultivate different ways of thinking about music, and one goal of the study is to compare the answers with a view to test this hypothesis. In other words, these five categories are a method to understand which effect the increasing levels of action–sound separation has on our experience of music, and should not be considered an *organological* classification of instruments. Kvifte (1989) has put forward a more scientific approach to new ways of classifying instruments, including electronic and digital instruments, and it is not my intention to suggest an alternative classification system.

An aside on electric instruments

There is a special class of instruments that is not described in the above categories, namely *electric instruments* such as the electric guitar. I wish to add a few comments regarding this omission. First, I emphasize that the above categories represent orders of action–sound separation—they are about what happens in the instruments, and not a classification system of instruments per se. Second, electric instruments should not be seen as belonging to a unique order of action–sound separation, because they feature electronically amplified acoustic sounds. In the scheme of the categories presented in this section, I would say that an electric guitar is a direct instrument with varying degrees of electronic *effects*. Following the same logic, a singer singing through a microphone is an incorporated instrument with electronic effects. Electronic and digital effects should be considered additions to instruments and controllers.[11] The importance of the electric guitar in the development of rock music shows that electronic effects in the amplification process have had a major impact on the music of the past several decades.

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[11] The difference between instruments, controllers and effects is a controversial topic, but in the context of this thesis, I do not intend to delve into this discussion.

4.3 Toward New Roles in Music

With the advent of digital musical instruments, the relationship between performer and sound became an arbitrary one (Brown et al. 1996). Brown et al. (ibid. 28) recall how expectations that digital technology would liberate the composer from the constraints of acoustic instruments gradually matured into the realization that, paradoxically, composers became more involved with the design and implementation of instruments. A consequence of working with DMIs seems to be that instrument design, composition and musical performance are becoming fused into a process where the same person switches between two alternating modes. In “run-time-mode”, the musician is the composer/performer, and in “edit-mode” the musician is the instrument designer/composer (Jordà 2005: 20). These modes are essentially the same as the phenomenological modalities of *ready-at-hand* and *present-at-hand*, which are concepts that were introduced in *Being and Time* by the philosopher Martin Heidegger (1962). According to Heidegger, a tool is ready-at-hand when in use, and present-at-hand when the tool breaks and the user needs to fix it. Heidegger’s point is exemplified by a carpenter who uses a hammer for its purpose without consciously thinking about the hammer itself. However, when the head falls off the hammer, the tool becomes the focus of the carpenter’s attention and he sees the hammer in its true phenomenological light. A survey conducted by Magnusson and Mendieta (2007) exposed that many musicians with experience of both playing acoustic and digital instruments see the computer as a distracting tool that does not lend itself to deep concentration, because of the need to constantly switch between the two modes of being ready-at-hand and present-at-hand.

This blurring of traditionally separate roles in music is seen in many areas where DMIs are used. Freeman (2008) challenges the classical view of music as something that is created by a composer, to be interpreted by performers, and finally passively perceived by an audience. He argues that such a view, which he calls a “feed-forward network”, idealizes the composer as the sole source of music. In this classical view, the composer is seen as someone who receives “divine inspiration” and translates this into a score. Performers translate the score into sound, and the audience is supposed to sit passively and not disturb the “magic of the moment.”

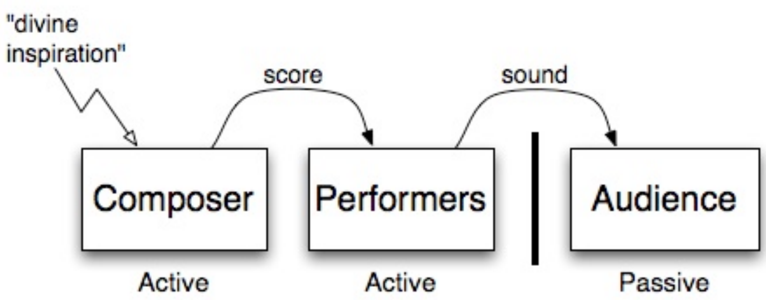

Figure 4.2. Feed-forward network. The composer and performer are seen as active in the creation of music, while the audience assumes a passive role with no influence on the music (Freeman 2008).

Freeman suggests that technology can provide ways to empower the audience's influence on the music-making process, turning it into a "feedback loop". In this context, the "composer" is the designer of the instrument, and music is created by performers and/or an audience who interact with the environment set up by the designer. Such environments can be realized in a number of different ways: Cameras may set up to detect motion in the audience, individual controllers may be handed out, etc.

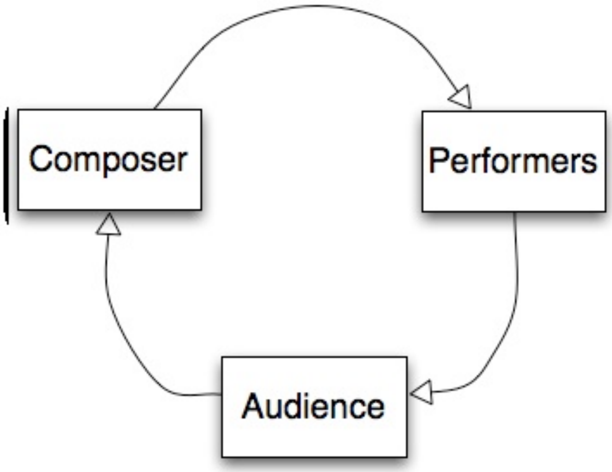

Figure 4.3. Feedback loop (Freeman 2008).

I believe that giving the audience a degree of influence on the musical result could be one way of de-mystifying DMIs. It increases interaction between performers and the audience, and between individuals in the audience. Cleverly designed interactive musical environments could prove to be both aesthetically rewarding and educational, because it introduces the audience to DMIs in a hands-on fashion, providing the ability to understand what is happening in the program. As I have mentioned earlier, I think such an understanding is a key to fully appreciating the real-time performance of DMIs.

In the same way as the advent of digital musical instruments is blurring the divisions between the traditional roles of composer, performer and audience, it has also introduced a new continuum between sound engineer and live musician. Certain groups of performers, for example DJs, can be said to belong to both categories. Depending on their performance style, some DJs are more towards the live musician end of the scale than others. Club DJs have taken the art of interweaving tracks, rhythms and effects to a level that borders on composition, creating layers, textures and musical forms that can be accredited the DJ as much as the musicians behind the recorded material on the various source tracks. The playback and spatialization of electroacoustic compositions—referred to as *diffusion*—is also often considered a live performance due to the intricate details that need to be considered in the process of adjusting the sound according to a *diffusion score* (Pasoulas 2008). Contrasted with the more traditional view of a sound engineer as someone who modifies the sound of music performed by musicians, the processing of sound in electroacoustic performances is considered an integral aspect of the music making process. According to my definition in Chapter 1, real-time performers of DMIs are placed on the far "live musician" end of the sound engineer–live musician continuum.

4.4 Conclusion

In this chapter, I have focused on the cultural significance of new technology, and presented a view of cultural development as "resonating" in an interplay between natural and cultural forces of influence. Discovering new affordances created by technological advances is an orientation process which may take years or decades, and may challenge existing paradigms in music. DMIs are seemingly beginning to challenge traditional concepts in music. I have also presented five categories of instruments based on order of separation: incorporated, direct, mechanical, analog electronic and digital. These five categories form the basis of the empirical study in Part II.

Part II

Empirical Study

Chapter 5 – Methodology

My decision to divide this thesis into two parts—one theoretical and one empirical—was taken quite early in the preliminary stages of research. My chosen topic entails a broad interdisciplinary overview, and I quickly realized that getting lost in mountains of theory would be an easy trap to fall into. I consider myself an advanced beginner in the research field of music technology, and I could think of no better methodology than to test my theories against the voices of musicians who are experienced DMI users. The empirical findings would serve as an anchor which would prevent me from drifting away from the shores of relevance, and which would provide me with insights that I may not have gained through theoretical research methods alone. A qualitative approach has been adopted for these purposes. In this chapter, I will provide a brief account of the methodological considerations involved in my empirical study.

5.1 Qualitative Research Interviews

This empirical study is based on qualitative research interviews with six musicians who are experienced users of digital musical instruments. The entire process, from planning the interviews through to reporting the findings, is based on Steinar Kvale's *InterView: En introduktion til det kvalitative forskningsinterview* (English: *InterViews: An Introduction to Qualitative Research Interviewing*) (1997). According to Kvale, the research interview is a process where knowledge is created in the conversation between the interviewer and the respondent. Kvale describes seven stages in the investigation process: *thematizing, designing, interviewing, transcribing, analyzing, verifying* and *reporting*. Section 5.3 in this chapter is devoted to an evaluation of my progress in each of these seven stages of the interview investigation. The conversations that took place were based on the so-called *half-structured* interviewing technique (ibid.), where a framework for the conversations was set by a list of basic questions that were meant to guide the conversations toward topics that are relevant to this thesis.

5.2 Selecting the Respondents

In Chapter 4.2, I presented five categories of instruments according to the *order of action–sound separation*: *incorporated, direct, mechanical, analog electronic* and *digital*. One original intention for the study was to select one representative for each category and compare their answers to test the following hypothesis: *Experience from instruments with different orders of action–sound separation may cultivate different ways of thinking about music*. It soon turned out, however, that the DMI performers that I considered for the digital instrument category in this survey, had originally started out playing acoustic or non-digital instruments in their early years, and many are still performers of both. This is hardly surprising. Digital musical instruments (especially for real-time performance) are so recent that few musicians active today have grown up without having been involved with other instruments before discovering DMIs. This background probably heavily influences their views, and they can hardly be representatives solely for DMIs in the same way as a violinist with no other instrumental background, for instance, would be a representative for the direct instrument category.

Furthermore, as the topic of my thesis is DMIs, it is more interesting to have a selection of participants who all are involved with DMIs on a professional level. I have, however, made sure that all instrument categories are represented through other instruments that the respondents play or have a background in playing. Table 5.1 below gives an introductory overview of the respondents, their respective digital and non-digital musical instruments and the categories they represent in the context of this study. Most of the participants play or have played more instruments than included in this overview, and have a wider range of DMI set-up. What is included in the table is what could be considered their most common DMI set-up for real-time performance and their main, or most influential, non-DMI instruments. A more detailed introduction to each respondent and the featured DMI set-up will be presented in the next chapter.

Respondent	**DMI**		**Main non-DMI**	**Categories represented**
	Controller	**Sound engine**		
Alex Nowitz	2 Wii Remotes	Laptop running LiSa & junXion	Voice	Incorporated Digital
Anders Vinjar	Laptop & accessories	Laptop running SuperCollider	Trombone Guitar	Direct Digital
Bugge Wesseltoft	Lemur / Novation Remote SL keyboard	Laptop running Live & SooperLooper	Piano	Mechanical Digital
Maja Ratkje	MIDI keyboard	Laptop running custom designed software	Voice	Incorporated Digital
Natasha Barrett	16-channel MIDI controller	Laptop running Max/MSP	Cello Guitar	Direct Digital
Rolf Wallin	Laptop or Controller Suit	Laptop running Max/MSP	Trumpet Piano Analog synthesizer	Direct Mechanical Electronic Digital

Table 5.1. The respondents, the featured instruments and the categories they represent.

At this point, some readers might raise objections against the criteria I have set for selecting my group of respondents, and wonder why have I not, for example, picked out musicians from a broader range of musical genres. I am certainly aware that this selection of musicians represents only a few musical genres, namely the electroacoustic, experimental jazz and avant-garde music genres. In my defense, I would like to reemphasize that this thesis is about the real-time performance of DMIs. These are, in fact, among the few genres, at least in Norway, that have established traditions of *creating sounds in real-time*, as opposed to selecting from banks of synthesizer presets or triggering preprogrammed sequences of sounds. As such, I suspect that having a selection of musicians from a broad range of genres would have produced less conclusive findings for my investigation purposes. Naturally, it would be interesting to conduct follow-up research based on other selection criteria.

5.3 The Interview Investigation in Seven Stages

In the following, I will briefly describe the entire qualitative investigation process, following Kvale’s (ibid.) seven stages.

Thematizing

Although the exact formulation of my main research question went through various revisions both before and after the empirical study, the main topic was quite clear from the beginning. Also, the idea of selecting a group of respondents based on the order of action–sound separation of the instruments they represent was planned from this stage. It was based on the above-mentioned hypothesis, which I was eager to pursue.

Designing

I wanted to strike a balance between technical, practical, musical and cultural issues, as I believed that the combination of these may be the reason why developing DMIs for real-time performance is complicated. Appendix A shows the questions (in Norwegian) I had set up as a guide for the half-structured interviewing method. I used the same guide for all respondents, but I was prepared to formulate the questions slightly differently depending on which respondent I was talking to. A part of the design process, then, was also to do some background research on the musicians. Also, I conducted a pilot interview conversation with a fellow student prior to the interviews proper. This was an important part of determining the conversation length and testing the relevance of the questions.

Interviewing

The interviews were carried out over the course of two months in the spring of 2009:

- Anders Vinjar (Oslo, March 12)
- Maja Ratkje, March 24 (Svartskog, March 24)
- Bugge Wesseltoft, March 31 (Oslo, March 31)
- Natasha Barrett, April 3 (Oslo, April 3)
- Alex Nowitz (Berlin, April 16)
- Rolf Wallin (Oslo, May 19)

The respondents had agreed to participate on the basis of a two-page introduction to the project (Appendix B), where the main focus was the description of the instrument categories based on the order of action–sound separation. Note that *electric* was an independent category at this point—it was later removed (cf. Chapter 4.2).

The interview was designed to last about 1 hour. However, the interview conversations turned out to vary greatly. The shortest lasted 35 minutes, and the longest was more than 90 minutes.

Transcribing

According to Kvale (ibid.), it often takes much longer than planned to transcribe interviews and analyzing the material. I certainly subscribe to this view. The process of transcribing the interviews left me with 80 pages of material to analyze. I used the software application HyperTranscribe,[12] which turned out to be an invaluable tool in the transcribing process. I transcribed the interviews *in verbatim*. Some exceptions were made when words or phrases were repeated, and I "smoothed over" phrase stumbling. Four of the interviews were conducted in Norwegian, while two of the interviews were in English. Natasha Barrett has English as her first language, whereas Alex Nowitz, who is German, has English as his second language. I have taken the liberty to rephrase some of Nowitz's formulations, with the intention of making his meanings clearer.

Analyzing

I adopted an *ad hoc* method of analysis (ibid.), combining the methods of *condensed meaning* (rewriting the meaning of the respondent in condensed form), *meaning categorization* (placing the meanings according to categories), *narrative structuring* (focusing on the plot of stories told) and *meaning interpretation* (interpreting the respondent).

Verifying

I emailed parts of the transcriptions back to the respondents if I felt that the meaning was unclear. Also, I sent what I have written about the participants' background and featured DMI set-up for verification. I received the texts back with some moderations.

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[12] http://www.researchware.com/products/hypertranscribe.html

Reporting

I have chosen to present the findings along the lines of some main themes that crystallized out of our conversations: *Developing the Instrument and with the Instrument, Operating in Different Domains, Performing with the Instrument* and *The Future*. I have attempted to keep a narrative style that ties the empirical findings to the theories presented in Part I of this thesis. However, I have decided to present quite a few direct quotations, because I feel that a certain level of informality could be refreshing after the relatively “heavy” theoretical style in Part I

Chapter 6 – The Respondents and Their Instruments

In this chapter, I will present the backgrounds of the respondents and their DMI configurations in more detail. Because of their differing backgrounds, working methods and artistic approaches, I consider this information a necessary context in which the findings can be discussed.

6.1 Featured Hardware and Software

Before presenting the respondents and proceeding with the findings, I will quickly run through the various hardware devices and software programs that will be mentioned during the course of the presentation of the participants and the findings based on the interviews with them. Further information can be attained by referring to the footnotes.

Hardware

The *Wii Remote*[13] is originally designed for Nintendo's *Wii* game console. One of the main features of the remote is its motion sensing capability enabled through the use of accelerometers, making it possible to detect movement in three dimensions and sending the control data wirelessly. Additionally, it has 11 buttons, which may be mapped to trigger various actions. Since its launch in 2005, the Wii Remote has received massive attention from hackers, and various software programs are available that enables mapping its controller function to non Wii-related devices.

Novation's *Remote SL*[14] is a two-octave MIDI keyboard controller designed to free the artist from being chained to the computer screen by placing all the relevant data alongside the relevant controls. It also allows for more detailed control of sequencers and plug-ins than do the more generic keyboard controllers on the market.

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[13] http://www.nintendo.com/wii/what/controllers

[14] http://www.novationmusic.com/products/midi_controller/remote_sl

Lemur[15] from JazzMutant is a multi-touch and modular controller for sequencers, synthesizers and virtual instruments (cf. Chapter 2.2, p. 14).

The *Peavey PC1600x*[16] controller surface is a large MIDI fader box with sixteen faders, sixteen buttons, a data wheel and miscellaneous other functions.

Software

LiSa[17] (short for Live Sampling) was developed at STEIM[18], and is a real-time audio manipulation environment that enables the recording, playback and audio processing of a large number of samples simultaneously. More than 30 parameters can be controlled in real-time.

junXion[19], also a STEIM product, is a connectivity (mapping) program that can process incoming data from a whole range of controllers (among them the Wii Remote) and route it to other MIDI or OSC controllable music and sound software or hardware.

SuperCollider[20] is an environment and programming language for real-time audio synthesis and algorithmic composition. The SC Language combines an object-oriented structure with features from functional programming languages with a C family syntax.

Ableton *Live*[21] is a loop-based sequencer designed as much for live performance as for production.

SooperLooper[22] is a free live looping sampler capable of immediate loop recording, overdubbing, multiplying, reversing and more.

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[15] http://www.jazzmutant.com/lemur_overview.php
[16] http://www.harmony-central.com/Events/SNAMM97/Peavey/PC-1600x.html
[17] http://www.steim.org/steim/lisa.html
[18] STudio for Electro-Instrumental Music: http://www.steim.org/steim/
[19] http://www.steim.org/steim/junxion_v4.html
[20] http://www.audiosynth.com/
[21] http://www.ableton/live
[22] http://www.essej.net/sooperlooper/

ImproSculpt[23] is a piece of software for live sampling and manipulation, especially designed to deal with improvised audio in real-time using algorithmic composition.

Max/MSP[24] is a graphical programming environment that allows the user to build patches out of modules, called objects. These can be combined in a virtually endless variety of configurations.

6.2 Alex Nowitz

Bakground

Alex Nowitz, born in 1968, is a singer and composer based in Potsdam, a suburb of Berlin, Germany. He is educated in both classical and electronic composition, and classical singing. He has composed vocal music, chamber music, electroacoustic music as well as music for dance, theater and opera (Nowitz 2009). As a singer and voice artist, Nowitz has developed several unique vocal techniques. Over the past 14 years, he has gone from baritone to tenor, and then from tenor to countertenor. He can also sing extremely low, using a technique that may resemble Mongolian or Tuvan throat singing. Additionally, he has a broad palette of unvoiced techniques consisting of sounds made by lips, tongue, constrictions in the throat and other unvoiced fricatives (Nowitz 2008).

Nowitz began experimenting with electronics while playing in various jazz hard-core bands in the 90s. At some point, however, he became disillusioned with electronics, and a ten-year period followed where he only performed vocals acoustically besides composing. In 2007, he felt the time was ripe to start experimenting with electronics once more. A residency at STEIM in Amsterdam followed, which took place in 2007-2008. Here, with the assistance of software developers at STEIM, he created a set-up that he has integrated into his current vocal performance (interview 04.16.09).

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[23] http://improsculpt.sourceforge.net/pmwiki/pmwiki.php
[24] http://www.cycling74.com/products/mmjoverview

Featured set-up

Controllers	Sound engine
2 Nintendo Wii Remotes – one for each hand	Laptop (MacBook Pro) running LiSa and junXion

Nowitz's vocals and the ambient sound from separate microphones are routed via a sound card into the computer and the LiSa software. Outputs from the Wii Remotes are transferred wirelessly to the computer, and goes via the program junXion into LiSa as control data. This set-up allows him to sample his own voice and process it in real-time using the Wii Remotes. He also has a bank of prerecorded samples (exclusively from his own compositions). Each Wii Remote is equipped with 11 buttons, a total of 22 buttons. One specific action is assigned to each individual button. Some of the basic processing functions include two record modes (which record either the ambient sound or his voice), normal playback, playback at variable speeds, forwards and backwards (making scratching possible), pitch shifting, volume control and switching between samples.

The most important function of the Wii Remote is the possibility of mapping motion data in three dimensions. With one of these controllers in each hand, Nowitz is able to control data in six dimensions just by moving his hands and arms. Although the mapping is relatively straightforward (directly mapped to parameters such as amplitude and pitch shift), the combination of the motion data and the 22 buttons can yield very complex results without it being too cognitively taxing in a performance situation. Nowitz explains that the mapping is carefully designed to suit his performance style. Even before he started integrating electronics in his performance, he was already moving in much the same way as he does when using the Wii controllers. He calls himself a "Klangtänzer"[25]—a "sound dancer" (interview, 04.16.09).

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[25] For examples of Nowitz's performances, see:
http://cec.concordia.ca/econtact/10_4/video/nowitz_musicforsinger.mov and
http://cec.concordia.ca/econtact/10_4/video/nowitz_selfportrait.mov

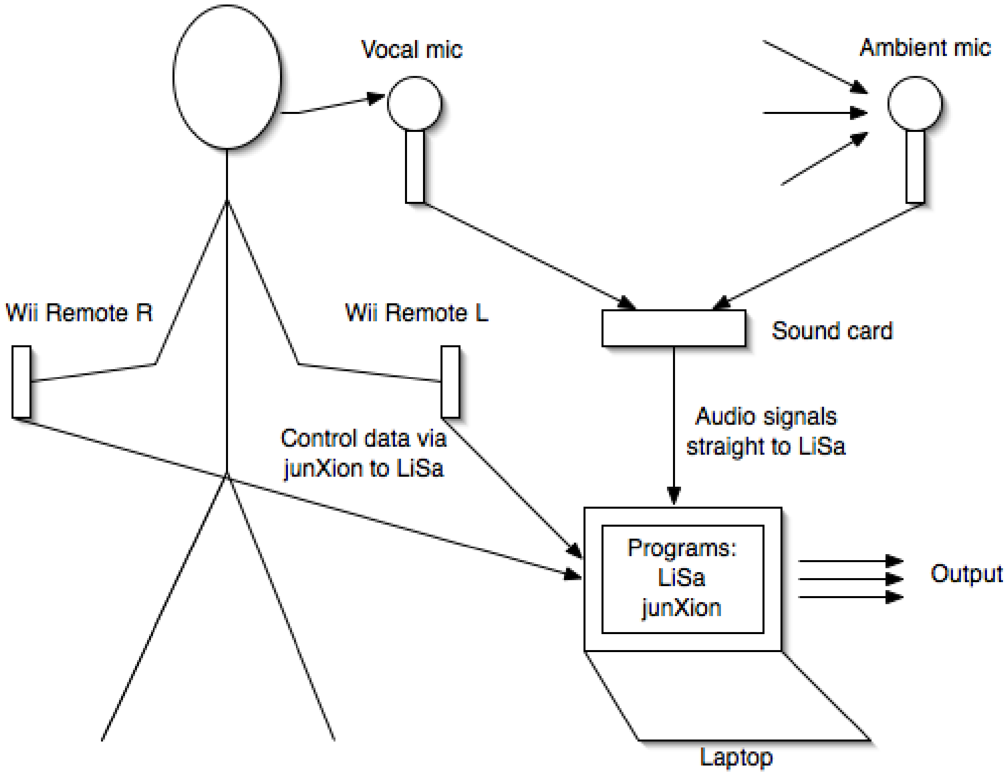

Figure 6.1. Alex Nowitz's "sound dancer" set-up.

6.3 Anders Vinjar

Background

Anders Vinjar, born in 1963, is a Norwegian composer. His work can be roughly divided into the domains of instrumental music and electroacoustic music. On the instrumental side, he writes both solo works for various instruments and music for ensembles, often including electronics. His electroacoustic music, on the other hand, is based on his own computer programming and created in the tradition of *musique concrète*[26], where the sound objects are what carry the music structure. His output includes electroacoustic music, instrumental music, videos, dance-, theater-, radio-shows, web-projects, installations and soundscape-projects.

Vinjar has a multi-instrumental background, and has gone through formal education both as a trombone player and as a guitarist. He has been working increasingly with

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[26] A form of electroacoustic music championed by Pierre Schaeffer (c.f. Chapter 3.1, p. 32).

music on computers for the past two decades, and gradually became more focused on composing rather than performing music. His performances mainly involve diffusion of electroacoustic works, and he occasionally performs live electronics.

Featured set-up

Controllers	Sound engine
Computer keyboard, mouse, occasionally other external sensors	Laptop running SuperCollider.

In the past few years, Vinjar's preferred software for live performance has been SuperCollider, in which he works directly with the music parameters using the SC Language. He writes commands into the program window, evaluates the code and makes adjustments on the fly. He also uses the mouse actively as a controller, typically setting up a patch and allowing for the mouse actions to hone in on something until it sounds right. Alternatively, he occasionally records a mouse action and uses it as control data in some way or another. It is the laptop itself, however, that is the hub of his live electronics performance. For the kind of real-time sound processing that he does on stage, he finds this SuperCollider to be more programmable and flexible than graphical environments such as Max and Pure Data (interview 12.03.09).

6.4 Bugge Wesseltoft

Background

Jens Christian Bugge Wesseltoft, born in 1964, is a Norwegian jazz musician, pianist, composer and producer. During the 90s he, along with other contemporary jazz artists, ushered in the use of electronic sounds as a central structural element in a genre that came to be known as Future jazz, a term coined to describe the Norwegian version of nu jazz[27]. Bugge's career so far has seen him gradually moving from more or less traditional Nordic jazz toward more free improvisational forms, from note-oriented music to the exploration of timbre. In the past few years, he has been

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[27] http://en.wikipedia.org/wiki/Nu_jazz

developing a solo project, performing mainly on the piano and sampling his own playing and manipulating it in real-time. His performances are completely improvised.

His father an accomplished jazz musician, Bugge grew up surrounded by music and he started playing the piano at the age of three. Save for a short period of receiving piano lessons, he has never had any formal musical education. He has, however, always had the benefit of playing together with good musicians, some of whom he considers his mentors. In addition to playing the piano, Bugge played the tuba and the bass drum in the school marching band. At the age of 16, he started playing in bands and he soon became interested in electronic sounds. He bought a Fender Rhodes, and for a 10-year period he played mostly synthesizers and electric pianos before returning his focus to the piano. Fascinated by the combination of acoustic instruments and electronic sounds and rhythms, he has stuck with a piano/electronics set-up since the early 90s (interview 31.03.09).

Featured set-up

Controllers	Sound engine
Lemur from JazzMutant Novation Remote SL keyboard	Laptop running Ableton Live and SooperLooper

Although he has performed using very many different configurations during his career, Bugge does have a more or less permanent set-up for his recent solo project that forms the hub of his real-time sampling and audio processing activities. First of all there is the piano, a grand piano with a microphone to catch the sound of the strings, the soundboard and the resonating space inside the piano. This is routed via a sound card into his Macintosh laptop, running Live and SooperLooper. The acoustic source sounds are routed into both programs in parallel, allowing Bugge to control samples and effects in various different ways using Remote SL and Lemur. He plays his piano, records loops and builds up an improvisational framework of sounds, which he then starts playing with.

Figure 6.2. A typical acoustic/digital hybrid performance by Bugge Wesseltoft, here live in San Sebastian, Spain in 2008.[28]

6.5 Maja Solveig Kjelstrup Ratkje

Background

Maja Solveig Kjelstrup Ratkje, born in 1973, is a Norwegian vocalist and composer. She composes both orchestral and electroacoustic works, and performs and releases music for concerts, recordings, films, installations, theater, dance and other performances. Throughout her career so far, Ratkje typically has several ongoing projects at all times, and collaborates with musicians and artists from a wide variety of genres. Her compositions and performances cover the range from more or less traditional orchestral music to experimental noise. Ratkje uses electronics as part of many of her performances.

Ratkje started playing the violin and piano at the age of four or five. She grew up participating in school musicals and music theater. Later, she studied composition at the Norwegian State Academy of Music from 1995 to 2000. This was when she grew interested in electronics. With access to the academy's music studio, she spent long hours learning about studio production, sound processing and experimenting with any piece of equipment she could get her hands on. She discovered that the process of trial

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[28] Image taken from http://www.heinekenjazzaldia.com/?page_id=246&language=en

and error often gives unexpected and interesting results, and it has become one of her guiding principles when working with electronics (interview 24.03.09).

Featured set-up

Controllers	Sound engine
MIDI controller keyboard	Laptop running custom-designed software

First and foremost, Maja Ratkje is a vocalist when performing live. Her vocals are also a central element in her various electronics configurations on stage. Her main source of electronic material is her own voice sampled in real-time, occasionally supplemented with prerecorded samples. Recently she has been using a laptop running a custom-made program that she has developed in collaboration with Øyvind Brandtsegg. This is based on ImproSculpt, which is another one of Brandtsegg's programs. This program suits her needs, allowing her to operate with several musical layers simultaneously. She usually uses a MIDI controller keyboard to control Brandtsegg's program.

6.6 Natasha Barrett

Background

Natasha Barrett, born in 1972, is a composer and performer of electroacoustic art music. Originally from the UK, she now lives and works in Norway. Her work spans concert electroacoustic and acousmatic composition through to sound-art, large-scale installations and live performances. Of particular interest in the context of this thesis is her live improvisation, where she samples musicians improvising on acoustic instruments and submits the sampled material to sound processing and compositional structural manipulation, all in real-time. One such project is DrOx, a duo featuring Tanja Orning on cello and Barrett herself on laptop.

Barrett studied classical guitar and cello during her first music degree, turning her focus toward composition for her master's degree at the University of Birmingham in 1994. She began working extensively with electroacoustic composition, and the study also gave her the opportunity to work with BEAST (Birmingham ElectroAcoustic

Sound Theatre). She carried on electroacoustic composition through a doctoral degree supervised by Denis Smalley, awarded in 1998 at City University in London. In the same year, she came to Norway on a grant from The Research Council of Norway and spent ten months at NOTAM (Norwegian Center for Technology in Music and Art). She now works freelance as a composer, sound-artist and researcher, based in Oslo.

Featured set-up

Controllers	Sound engine
16-channel MIDI controller	Laptop running Max/MSP

Most of Barrett's performance instruments are Max/MSP patches that she has built. The patches are designed to handle real-time acoustic sampling, logging, recycling, layering and transforming of sound and control data allows temporal-structural retrieval of that from the past, interaction with the present, and anticipation of the future.[29]

For controllers she has tried various different devices ranging from homemade light sensors, proximity sensors or anything she can control with continuous movements of her hands or body, using foot pedals for switches. However, she has come to the conclusion that these sensors are too unreliable in performance. Now she predominantly uses a Peavey PC1600x controller surface. The reason she gives is that it's very exact, it's quite robust and she knows when she does something what she is going to get out of it (interview 03.04.09).

6.7 Rolf Wallin

Background

Rolf Wallin, born in 1957, is a Norwegian composer, trumpet player and avant-garde performance artist. His musical career spans several decades, and he was an early proponent of using electronics both in composition and performance. His music is often referred to as genre defying, and he is renowned for having developed several

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[29] Accessed April 2009: http://natashabarrett.org/DrOxInfo.html

unique compositional techniques. As a performance artist and sound artist, Wallin has gained a reputation for incorporating the use of highly unusual instruments.

Wallin started playing trumpet in his school's marching band as a young child. At the age of eleven, he had written a few melodies, which alerted the conductor's interest. The conductor was a music student at the University of Oslo at the time, and he offered Wallin private tuition in four-part harmony. With this starting point, he ventured on to graduating from Foss High School of Music and then studied composition and pedagogy at the Norwegian State Academy of Music from 1976 to 1982. Meanwhile, he was actively performing with several experimental jazz and rock bands well into the 80s. In the mid-80s he spent a year at the University of California, San Diego, where he first got into programming. Now mainly a composer, he tries to make his work as fun as possible by doing many different things, ranging from orchestral music through installations to the more avant-garde projects he is involved with.

Featured sep-up

Controllers	Sound engine
Laptop, Controller Suit, other controllers	Laptop running Max/MSP

In terms of controllers and the particulars of his Max/MSP programming, Wallin's choices are dictated by the piece of music he is performing. I find his Controller Suit (pictured)[30] particularly relevant in the context of this survey due to its uniqueness as a completely custom-made controller. He developed this suit in collaboration with NOTAM for the real-time performance of a piece entitled *Yó*. The suit has eight strips made of semi conductive plastic (cut out from anti-static plastic bags) attached to the sleeves and chest area. Additionally, it has 16 contact points on the hands, the collar and by the pockets. Contacts on the fingertips conduct voltage to these sensors. The plastic stripes send analog signals dependent on which area that is being touched,

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[30] http://www.notam02.no/index.php?/eng/Technology-and-Text/Hardware/Controller-Suit

while the contact points function as on/off switches. The control data can be sent wirelessly to the Max/MSP patches WiFi[31].

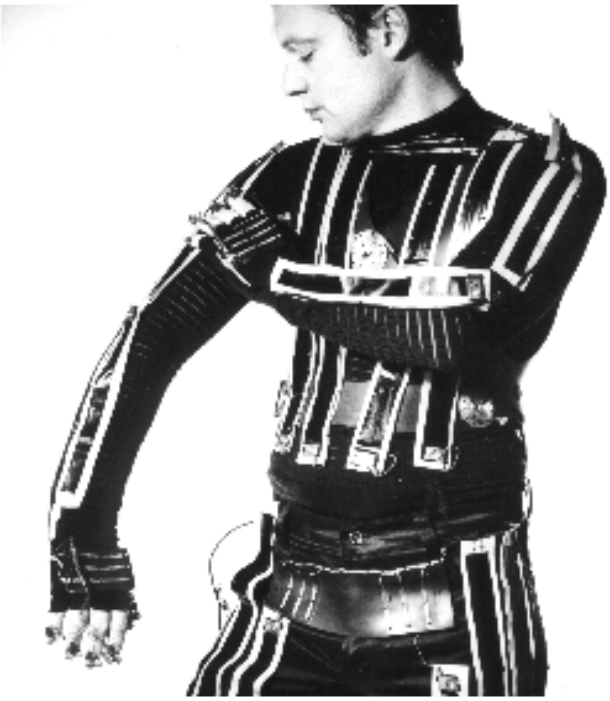

Figure 6.3. Rolf Wallin’s Controller Suit. Photo: Eli Berge.

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[31] http://en.wikipedia.org/wiki/Wi-Fi

Chapter 7 – Findings

With the previous chapter as a backdrop, we can now turn our focus to the issues that confront the participants in their work with developing their digital musical instruments. However, it is my view that their work on the DMIs cannot be seen as isolated from other broader questions central to their development as artists. Their DMIs are highly personal and adapted to their own ways of working with music. In order to gain insights into tendencies transferable to the field of DMI development in general, this survey takes into account how the respondents work with and think about music as a whole. Some main themes seemed to crystallize out of our conversations; this is probably influenced to a degree by my line of questioning, but the themes also tended to emerge without prompting. It is therefore a natural choice for me to present my findings along these lines. Unless otherwise noted, all paraphrasing and citing of the respondents are based on the interview transcriptions.

7.1 Developing the Instrument and With the Instrument

Issues in regards to instrument development

All of the survey's participants are involved in the development of their DMIs to varying degrees. I asked them what typical problems they face in the development process. Mapping issues seems to be a frequent stumbling block, although they mostly describe it without referring to the actual term.

Bugge Wesseltoft talks about wanting to be able to control as many parameters as possible. He is currently implementing the Lemur multi-touch controller in his work with new patches. He claims that he wants to "get in behind the program" and then control the parameters. From this explanation I gather that he is talking about figuring out clever mappings between the Lemur and the software. He expresses the opinion that there are no real limits; it's only a matter of finding out how to do it.

Rolf Wallin designs his configurations to work as an intuitive extension of the body. He assigns various curve filters to parameters to make his controller actions match their intended meanings. As this explanation may seem somewhat cryptic to the reader, I will attempt to make it clear. Human perception and human action is nonlinear in nature. A stepwise increase in the physical magnitude of any naturally occurring phenomenon does not necessarily result in an equal amount of perceived increase in magnitude by our senses. For instance, a doubling of the frequency of a tone results in us perceiving an interval of one octave. To our senses, each octave feels like equal steps, while the physically measurable increase is exponential. The same goes for our perception of loudness; the physical increase in the amplitude of the sound waves rises nearly exponentially while we hear a linear increase in loudness. This nonlinear/linear relation between physical occurrences and our perception features in all of our senses, which can be seen as inputs to the human body. It becomes increasingly complicated when we consider outputs from our body. Actions, or in this particular case gestural cues, are also nonlinear in relation to their intended meanings. If, for example, I were to move my arm back and forth between two points, A and B, to symbolize going up and down one octave, the movement of my arm from A to B would typically start out more slowly and gradually pick up velocity as it approaches B. The arm movement back again from B to A would be similar, i.e. starting slow and picking up speed. If the velocity of these movements were mapped in a linear fashion to span an octave, it would result in a tone gliding up and down the octave in an asymmetric and uneven fashion. With this mapping, the only way to achieve a linear gliding of the tone up and down would be to move my arm back and forth in a robotic manner. In either case, the relation between the action and the sound would not appear to be strictly coupled. The way to remedy this disconnect is to use so-called curve filters to compensate for the difference, thereby making the relation seem natural. This, speaking in general terms (the example using the octave as a parameter is my own contribution), is what Wallin is talking about when he says, gesticulating with his arm: “I try to achieve the same relation from here to there as from there to here, so that it feels right.” Assumably, what he has in mind with the hypothetical gesture accompanying this statement is the semi-conducting plastic strips on his Controller Suit, which can send continuously fluctuating data depending on the position of a finger on any one of the strips (the picture above apparently shows him in mid-action).

Natasha Barrett points out that it is possible to achieve impressive sound transformations with the simple click of a button, while making a complete disaster with the most complicated controller. She explains that her choice of controllers is a matter of optimizing her own cognitive capacity, and in order to do this, she prefers many simple controllers to one or a few complex controllers:

> This is a key issue. […] When we play an acoustic instrument, we are controlling *one sound*. That's like controlling *one object* in a Max patch, like an object which is used for granulation. But what I'm interested in my Max patch is controlling a thousand objects. Not only granulation, but all kinds of pitch shift, all kinds of temporal changes, all kinds of mixing and layering and cutting and splicing you can think of. And for that, I actually need simple controllers to control. So, to have one complex three-dimensional controller isn't going to help me with that kind of Max patch, where there is a very complex organization of sound-making objects and control-making objects. Which is very, very different from playing an acoustic instrument, where you have a very high degree of control over a very limited sound world.

She concludes that her brain could cope with many one- or two-dimensional controllers, but it could only cope with a very limited number of three-dimensional controllers, simply because of the capacity of our mental processing of information.

Alex Nowitz has taken a comparatively minimalist approach with his Wii "sound dancing" set-up. He works with relatively few parameters, and the mapping is quite straightforward. The combination of moving both his hands in three dimensions in addition to the 22 buttons, however, yields very complex results. He explains that even after using the set-up for more than a year, he still needs to have a list in front of him showing the various controller actions and their mappings to parameter functions when rehearsing before shows, especially if some time has elapsed since his previous Wii performance.

In the development process, Maja Ratkje finds herself frequently sidetracked by the discovery of possibilities that she didn't have in mind to begin with. Thus, she often starts out knowing what she wants, but ends up with something different from what was originally planned. However, she points out that it often turns out better than envisioned, so this is not so much as problem as an intriguing insight into the way she works in the development process of her digital musical instruments.

For Anders Vinjar, being lead in unexpected directions is a goal in itself. In terms of development, he is currently mainly focusing on physical modeling in compositional structures. It is a process of constant experimentation, where he programs simulations of various natural phenomena, which he then uses to control music parameters on a compositional level.

> One example is gravity. You can make a physical model that […] produces parameters that are played by a piano. If you increase gravity, the piano will slow down. It will require more energy and this is something you will immediately hear as heavier music. That is, if it's directly mapped. […] You can change the direction of gravity, making it work sideways instead of downward – what happens then to the music structure?

The above example shows that Vinjar, in comparison with the other respondents, is more focused on the composition process than with technical performance-related issues. This is not surprising considering the fact that he sees himself as a composer and not a performer.

Growing with the instrument—Towards virtuosity

Becoming an expert at any kind of musical instrument involves a lot of practice. Musicians who are able to achieve a level of mastery associated with being experts in their field have typically spent several hours every day for a period of many years practicing their instrument. Recent research shows that a total of 10,000 hours of practice is necessary to become a virtuoso, regardless of so-called talent or lack thereof (Levitin 2007: 197). Expert performers of DMIs are no exception. However, because of the frequently impressively sounding results it is possible to achieve with apparently no effort in digital software, many people seem to be under the impression that DMIs, or electronic instruments in general, do not really reveal much about the person performing on them ("they're just pressing some buttons"). An often-formulated objection is that music performed on DMIs is less expressive than acoustically performed music. Unsurprisingly, the survey's respondents do not agree. Anders Vinjar points out that this view is based on a misunderstanding:

> It's totally dependent on how [the instrument] is used, and what it is used for. […] Naturally, much of the use [of DMIs] is less expressive. The musicians are not as trained. Music and musicianship hasn't been developed to the same degree. Only within a few narrow fields has it been developed properly.

Vinjar's rebuttal is interesting, because he does not flat out reject the criticism, but rather deflects it with a fine distinction. While admitting that much music performed on DMIs lacks expressivity, he attributes this to poor musicianship. The instruments or the music itself is not the problem.

Based on these reflections, we may conclude that working with the development of a DMI is an exploration ground with two fronts. One the one hand, the instrument itself needs to be developed, and we have seen some of the issues that the respondents are confronted with in this process. Equally important, however, is the performers' own development, and the development of a culture of music and musicianship associated with the instruments. After all, the instrument is only the medium through which a musician creates an expression. In order to do so successfully, a musician must grow with the instrument; it is a mutual process of adaptation.

7.2 Operating in Different Domains

A central question in my survey was whether there is any difference in the way the respondents think or feel when working with DMIs compared to their other instruments. This yielded many interesting answers. It further emerged that their work can be seen as alternating between different domains in a variety of dimensions. Some of these alternating working modes are directly related to the instruments they play, while others are relevant to the music in general.

Composition, performance and instrument design

As described in Chapter 4, the boundaries between the traditional roles of composer, performer and listener become unclear in music created for and performed by means of digital musical instruments. These boundaries will most likely further disintegrate in the future as the use of digital musical instruments becomes ever more interactive. However, it still makes sense to make the distinction between the combined role of the composer/performer/instrument designer on the one hand, and the role of the audience on the other. For the time being, music is to a large extent a package prepared by the former to be enjoyed or taken in by the latter. As for the role shifting between composition, performance and instrument development, the degree to which the respondents view them as three separate domains varies.

Although he calls himself a composer, Vinjar points out that when working with computers, the composer-performer divide disappears. In most cases, they are the same person. Vinjar's development of his own set-up is simultaneously a process of creating compositional structures and the trying, testing and execution of diffusing[32] the work for an audience. When writing instrumental music, on the other hand, he is a composer in the more traditional sense, writing scores for other performers.

In some cases the instrument itself could equally be a work of art as the music that can be made with the instrument. *Feelings*, a work by Wallin and Simen Svale Skogsrud[33], is a good example. This installation bases itself on brainwaves measured by an EEG device. The installation is placed in a public space, such as a gallery lobby or a shopping mall. People passing by are invited to have two electrodes placed on their head while sitting in front of a screen watching a short film. Their brainwaves are used as data to control piano music based on the "feelings" the brain is sending out. Music coming out of the installation is always new, because it depends completely on the user's body states as he or she sits in front of the screen and lets the EEG device track his or her brain waves. The music is not composed—the instrument is.

As for performance, Wallin performs music in three circumstances: With an amplified balloon when performing the work *Scratch*, with the Controller Suit when performing *Yó*, and with live electronics when performing his own electroacoustic works. Apart from this, he sees himself mainly as a composer.

Bugge's performances are completely improvised, and so every performance is simultaneously a composition of sorts:

> […] It is really just a platform to create interesting improvised structures. I've come to realize that I need to have frameworks for the various improvisations so that I don't stand completely free within each part. Rather, I can […] use what is possible within the frameworks for each part, thereby giving a larger form to the concert.

The frameworks themselves are also created on the spot. The sampling, looping and organization of sounds, which constitute the building of these frameworks, are also an integrated part of the performance.

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[32] For more information about the potential complexity of electroacoustic diffusion systems, see http://en.wikipedia.org/wiki/Birmingham_ElectroAcoustic_Sound_Theatre

[33] http://svale.org/

Barrett explains that she has two types of Max patches, or two approaches to Max programming. One is where the Max patch is part of a live electronics composition. In these cases, the patch is locked to a larger idea of the score. It also involves the acoustic performer, whose performance is an integrated part of the set-up. This is somewhat closer to the traditional idea of performing a composition than her live performance patches, where she performs an improvisation along with an acoustic performer. These patches are designed in a way that makes it possible for her to log and capture everything they do live in her Max patch. This enables her to retrieve what she needs in the middle of a performance and develop it through the use the compositional control building blocks that are a part of the patch. She summarizes:

> It's two different approaches. I might use some similar types of sound transformation, some similar type of organization, but it's different approaches, because one is completely calculated based on the score, as a composition. The other, I have no idea what the performer I'm playing with is going to input.

As a composer of more or less traditional classical music on the one hand, and an avant-garde voice artist performing with or without electronics on the other, Nowitz explains that his approach to music varies depending on which domain he is working in. When composing chamber or orchestral music he follows certain compositional ideas, acknowledging the fact that these are commissioned works for audiences with varying musical preferences. A convergence of the composer and performer domains occurs when he writes music for some contemporary theater and dance performances, where Nowitz himself performs the score live throughout the show, creating a collage of sounds with his various vocal techniques. Here, the roles of composer and performer, while still separable, become more fused; the score is based on his performance *and* the performance is based on the score. The distinction further disintegrates when the Wii set-up is used. The instrument itself is composed by the performer and performed by the composer. Clearly, the traditional division between the roles of composer, performer and instrument designer becomes fuzzy at this point.

Ratkje has adopted an integral approach that allows her to reap the benefits of being both a composer and an improvisational performer, claiming that she improvises with the mind of a composer, and composes with the mind of an improvisational musician (interview 24.03.09).

The perspectives presented above all seem to confirm the notion that the separation between the roles of composer, performer and instrument developer becomes less clear when working with DMIs. The distinction between these domains makes more sense when looking at how the respondents work with more traditional instruments and music.

DMI vs. non-DMI

The way the respondents' approaches differ when performing with or writing music for their DMIs as opposed to other instruments is, in my view, one of the keys to gaining a better understanding of which challenges the field of DMI development are facing today. It also provides vital data for comparison between the different instrument categories defined in Chapter 4.2. I have therefore paid particular attention to which non-digital instruments the respondents have based their replies on.

Ratkje explains that the main difference when playing electronics[34] as opposed to singing is that she uses more mental capacity on the technical aspects of the instruments when using electronics.

> […] Although I'm very familiar with the equipment it doesn't feel like I do things as spontaneously as when using my voice. […] Of course, there's more of a lag in the system, and it's more difficult to control several layers at once. When only singing I can just, you know, close my eyes and sing. […] I mean, it sounds so simple in comparison.

In other words, Ratkje feels that the immediacy that she has in her voice is lacking when playing electronics. However, she points out that she probably would have felt the same way about the piano if that had been her accompanying instrument. She explains that she has been working hard on developing her voice for a period of 10-15 years, and that it would require a lot of effort to attain the same level of virtuosity in DMI performance at this stage. Explaining that she would love to be able to control a great number of parameters at once, that would however divert her focus even more toward thinking like a technician while performing, which is difficult. "It takes a lot of practice. It's like rehearsing a violin, you need to become good at doing it," she concludes.

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[34] Ratkje uses both digital and analog electronic instruments. In this reply, I can only assume that she is referring specifically to DMIs, as opposed electronic instruments in general.

Also a singer, it is interesting to see whether Nowitz's comparison between performing with his Wii set-up and using only his voice is in concurrence with Ratkje's comparison. To a considerable degree, it is:

> The difference is pretty much comparable to any other instrument. [...] Difference is that the voice can be used in an absolute direct manner, if you're trained in using the voice. Meaning, what you think, you can immediately express with the voice in a musical manner. Whereas if you're playing an instrument, you're always dealing with any sorts of techniques. If you're playing guitar you're dealing with fingers and where to put the fingers. If you're dealing with a saxophone, same with key claps. If you're a pianist, where to put the fingers on the keys. And the thing with playing remotes and electronic instruments is that you have to learn your own set-up—the way you have designed it, actually. Which button triggers which action. So this is something you have to learn. [...] And on the other hand, you have to learn how to move in order to get the musical result you want. So these relations, you have to learn. And then you also have to consider that... and that's a funny thing, we always think that it's really real-time if you're dealing with live electronic music... with computers. That's not true, and it cannot be true because of physics. It's always a little bit later. It's actually always too late. And in that sense, the voice is always faster because it connects the brain into the body directly. The body, the voice, is the instrument.

Ratkje and Nowitz, who both view the voice as their main instrument, underscore the immediacy of the voice as opposed to other instruments in general—not just electronics. They point out that controlling electronics is something that takes practice on the same level as any other kinds of instruments. They also comment on the inherent latency between action and sound in digital musical instruments. As for differences, Ratkje attributes her inability to match the spontaneity her voice has when playing with electronics to the fact that she has focused more on training the voice, while Nowitz expresses the opinion that the immediacy of the voice can never be completely matched in other instruments—he sees it as a natural constraint. Nowitz is extrospective and looks at the physical nature of things. Ratkje's explanation is introspective and about her own priorities.

Barrett stopped performing with acoustic instruments in 1994 when she made the choice to focus on composition. She still has her classical guitar and cello, and she explains that she sometimes plays them just to get back in touch with the physical vibration of the instruments:

> I sometimes feel the need to have this acoustic resonating body under my fingers [...] to be in touch with this soundboard, which is part of our biological understanding of the world. [...] So, yes, sometimes I do pick up my instruments, but it's more to feel in touch with the acoustic resonance and the idea of the touch with the body around the instruments. Guitar and

> cello are very much enveloping type of instruments, where you are wrapped, really, around the body – the acoustic body.

According to Barrett, feeling the vibration of the instrument while playing—*haptic feedback*[35]—is precisely the reason why the level of control that is possible to achieve on acoustic instruments cannot be matched in DMIs. She claims that trying to make a digital instrument that can give a complete haptic image of the sound is paradoxical: It would require making an acoustic instrument. She points out that acoustic and digital instruments are two fundamentally different things. An expert performer of an acoustic instrument knows exactly what to do to get a certain type of sound. She questions whether it is desirable to make a copy of that, when there are more appropriate aesthetical issues which need to be addressed in the control of digital sound. She explains that acoustic instruments are single-dimensional devices, in the sense that whichever way we use (or misuse) the instrument it will always maintain the timbre associated with it. A violin will sound like a violin regardless of how we scratch, scrape or squeeze it. A computer, on the other hand, is a "hundred-dimension sound object". For Barrett, this calls for a completely different perspective:

> Technology centers are preoccupied with trying to make new controllers and new interfaces, and the more I work with these things as a composer and a performer, the more I realize that, actually, at least for me, I'm addressing different issues. Aesthetic issues.

From the perspective of being a composer, Barrett feels less inhibited when composing acousmatic (or electroacoustic) music on her computer than when writing music for acoustic instruments:

> […] You always have to make a decision; what note, what volume, what articulation you're going to play. And instruments are basically note and articulation based. Even if you make a sound which doesn't have a pitch focused to it at all, you still have to decide where your hand is going to be placed on the instrument. And, at least from a compositional point of view, you have to find a way to notate that on a piece of paper, which is still very locked to the Western notation system of a "note". […] Whereas, of course, with the computer I'm working with a much freer approach to sound, where I don't have to think about the Western notation system, or the Western performance system, and I can work with sound, primarily.

Vinjar, who also composes in the domains of instrumental and electroacoustic music, makes a comparison along the same lines. In electroacoustic music, the *sound* is the instrument, he explains. The sound objects (cf. Pierre Schaeffer's term, described in Chapter 3.1) that he uses is what carries the music structure. When he writes

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[35] Haptics, relating to the sense of touch, body position and motion as explained in Chapter 1, is a topic that has been omitted from this thesis.

instrumental music, on the other hand, he is much more focused on the note-based music structure: note patterns, phrasing, rhythm, etc. Despite the different working methods and approaches to music structure, Vinjar makes it clear that his basic mindset is the same regardless of instruments and medium.

Commenting on the difference in working with the piano as opposed to electronics, Bugge feels the two domains are getting closer to each other.

> I'm working more and more with timbre […] both acoustically and electronically. At least that's where I hope I'm headed. Looking at my background I guess I've always used piano to play harmonies and more […] "normal music" – music that is perceived as having melody and harmonies, while using electronics to create timbres and effects. But I'm working on getting these fields closer, in a way. Still, it's different. It's an acoustic sound source and an electronic sound source.

As opposed to Barrett and Vinjar, Bugge does not view his work as split between separate genres of music. Nonetheless, his description of habitually having used the piano for note-based music and electronics for the exploration of timbre is very similar to Barrett and Vinjar's comparison of instrumental music to electroacoustic music. The difference is that Bugge is striving for a symbiosis of the two approaches, whereas Barrett and Vinjar seem to prefer viewing them as separate methods of working. This, of course, could have to do with the fact that Bugge is not a composer in the sense that he does not write down music for other performers to play. His music happens in the spur of the moment, so he does not write music scores, like Barrett and Vinjar do.

Wallin also feels that the gap between working with computer music and instrumental music is getting smaller. He points out that when computer music started out nothing was anywhere close to real-time. Loading a patch or processing an effect entailed a lot of waiting, and there was no direct feeling of playing music. That difference is much smaller now, Wallin explains:

> Before, there was a sense of working more "with your head" when working digitally, and more "with your fingertips" when working analog. […] The difference is still there, but I think there is a much bigger overlap than earlier.

The "head vs. fingertips" dichotomy is a fitting example of the Heideggerian modalities of present-at-hand vs. ready-at-hand, described in Chapter 4.3. Wallin claims that digital music used to be more "brainy," because of the way one was forced to work with the programs. Then, as interfaces gradually became more graphically oriented and adapted to human perception, it became possible to work more intuitively in the digital domain. For Wallin, this enabled him to decouple from a previously very conscious working mode:

> You don’t really think about it anymore. […] I can typically be sitting up until 4 o’clock in the morning completely absorbed. The way I experience it now, my brain is just another fingertip, in a way. […] I sit and work for a long time and then go: ’Wow, what have I been doing now?’ You know, in the same way as when working more hands on.

In his comments above, Wallin is not referring to any specific instruments. He is making a general comparison between DMIs and traditional acoustic instruments. He does, however, make a valuable contribution that allows us to include analog electronic instruments in this empirical study. In the mid-80s when he was recording *Purge*, an electroacoustic work for percussion and tape, he worked with a Buchla synthesizer (Figure 7.1).

Figure 7.1. The Buchla synthesizer that Wallin used at Electroacoustic Music in Sweden (EMS).

This synthesizer from the 70s perfectly illustrates the very physical nature of analog electronic instruments. Wallin reminisces about the joyful hands-on experience of patching, moving sliders and twisting dials, which gave him a feeling of minute and real physical control. He describes it as "a big animal which you could get all sorts of sounds out of." The context of his relating this was my question about why he has stuck with sampling as opposed to synthesis when working with DMIs. This topic will be revisited shortly, but I find his explanation relevant in the current context as well:

> There was a long and painful period from this patch synthesizer era until you could finally have a control system and the generation – the synthesis or the sound processing – inside the same unit. So there was a long period of MIDI and Yamaha samplers, which was awful, because you were left with a system where there was MIDI [control] on one end and a synthesizer on the other end.

Although these comments were not made in reply to my question about the difference between DMIs and non-DMIs, they are, in my view, valuable input to this topic because they reveal Wallin's desire for having instruments that are designed as an entity; he wants an instrument to be more than the sum of its parts. Also, it shows that Wallin really wants to feel like his body is controlling the instrument—not just the brain.

Having been through DMI vs. non-DMI comparisons from all six respondents, we can now attempt to classify their answers. The table below provides an overview of which DMI and non-DMI instruments they have based their comparisons on, and is presented in order of increasing action-sound separation. I think the overview is a good starting point for further research. Although based on a small selection of musicians from different genres and with varying artistic outlooks, the answers within each instrument category do seem to resemble each other to a considerable degree. I think the findings lend considerable support to the hypothesis presented in Chapter 4: *The order of separation between action and sound in musical instruments cultivates different approaches to music making*. The incorporated vs. DMI comparisons show a much higher degree of contrast than comparisons between instruments with higher orders of separation and DMIs.

Digital vs.	Musician	DMI set-up		Non-DMI	Comparison
		Controllers	Sound engine		
Incorporated	Maja Ratkje	MIDI keyboard	Laptop running custom designed software	Voice	Voice more immediate Electronics accompany the voice and provides a multi-layered
	Alex Nowitz	2 Wii Remotes	Laptop running LiSa and junXion	Voice	Voice more immediate Electronics augment the voice
Direct	Natasha Barrett	16-channel MIDI controller with sliders / buttons /	Laptop running Max/MSP	Guitar / cello Direct instruments	Haptic feedback / different sense of control raises aesthetical issues
	Anders Vinjar	Laptop & accessories	Laptop running SuperCollider	Direct instruments in general	Note based structure in instrumental music / Structure based on sound objects in electroacoustic music
Mechanical	Rolf Wallin	Laptop or Controller Suit	Laptop running Max/MSP	Direct & mechanical instruments	Digital instruments more “brainy” Acoustic instruments more hands on. Difference is getting smaller.
	Bugge Wesseltoft	Lemur / Novation Remote SL keyboard	Laptop running Live and SooperLooper	Piano	Piano for harmonies, electronics for exploration of timbre Difference is getting smaller
Analog electronic	Rolf Wallin	Controllers in general	Sound engines in general	Buchla synthesizer	Sense of physical control in patch synthesizers compared to DMIs

Table 7.1. Participants’ comparisons between DMIs and non-DMIs.

Sampling vs. synthesis

One of the problems I was confronted with when preparing for this study was to make a decision whether or not to aim for an equal number of musicians who work with synthesis and sampling based sound processing. It soon turned out, however, that such a selection of respondents would not necessarily be representative of DMI performers. It seems that the trend, at least in Norway, for a majority of musicians who work with DMIs as of now is to depend on sampled sound sources, especially when performing in real-time. The building of sounds from scratch as one does in synthesis is a far more complex process than starting out with samples of acoustically complex material. Among the respondents, only Anders Vinjar works with synthesis to a considerable degree, using algorithms based on physical modeling. Upon asking the respondents whether they worked with synthesis, I got some interesting answers.

Ratkje makes it very clear that she eschews sound synthesis. She explains that she is fond of the somewhat uncontrollable, gritty quality of sound when it has an acoustic starting point. She further elaborates:

> Sound is so rich, and I know it would be tremendously complicated to make something that matches acoustic sounds. And I don't see the point either; at least not when I have developed ways of singing or methods of using my voice where I can get all the nuances I need for my music. [...] I don't need to spend several years learning synthesis that can match this. I see myself as a musician, and not a technician.

Ratkje has some experience with sound synthesis, but she realized that she would rather spend her time practicing, listening and learning, while haphazardly adopting equipment that comes her way.

Barrett is also mainly interested in acoustic sound sources because of their complexity. She does a little bit of synthesis in composition, but not much.

> I find it's very difficult with synthesis to make the same level of complexity [as acoustic sound]. But, having said that, that's actually one of my reasons to work with synthesis is when I want something that's very clear and straightforward and simple.

We have already touched upon Wallin's positive experience working with analog sound synthesis in the 1980s. In the digital domain, however, he has stuck with sampling. The reason he gives is that most of what came out at the time he was developing as an electroacoustic composer sounded "cold" and uninteresting.

> Sampled material […] has interest, which is energy in itself. […] When working with electroacoustic music, I think I'm very dependent on having something in the other end that I can 'speak with'. […] Something that comes from the systems themselves, from the music itself, or from the sounds themselves.

Wallin bought the first Yamaha DX7 (cf. Chapter 2.2) that came out in the 1980s, and was impressed by the sounds. He was quickly disillusioned, however, by the limited ways in which the synthesizer could be used: "It wasn't what I wanted in a synthesizer; an organism that you work together with, in a way. It was just like a Hammond organ with new sounds." Although he currently only works with sampled material, Wallin says that he would like to try working with synthesis again, because he knows that a lot of progress has been made in the field, and there are many new exciting methods for synthesis.

For Bugge, piano is the ultimate sound source for his work in the digital domain. He does have an analog synthesizer, which he occasionally uses as a sound source to work with digitally. In other words, he doesn't use it actively as a synthesizer, but as a source for sampling. He has some experience with sound synthesis: He has worked a great deal with FM-technology, using a Yamaha DX9, a spin-off product of the above-mentioned DX7. This version had an implementation that allowed for the processing of acoustic sounds through FM based modulation. He found this exciting, but he explains that he hasn't seen any plug-ins where this can be done directly in the programs he uses. "Now that [Ableton] Live is coming with a Max implementation[36], it will be exciting to see," he speculates. "Perhaps I can do it then."

All of the comments above are made by musicians who mainly rely on samples of acoustic sound in their DMI set-ups. However, their attitudes toward synthesis vary. Interestingly, openness to sound synthesis seems to increase in proportionality with the order of separation that the non-DMI instrument categories that the respondents represent. Maja Ratkje, who represents incorporated instruments, is the least inclined to use sound synthesis. Barrett, who has much experience with direct instruments, strongly favors sampling to synthesis, but uses synthesis for some specific purposes. Wallin, who composes music for both direct and mechanical instruments, is interested in trying synthesis now that the field has made progress since he experienced

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[36] http://www.ableton.com/extend

disillusionment with synthesis in the 1980s and 90s. Bugge, a pianist and therefore representing mechanical instruments, has some experience with synthesis, but he has not found an ultimate way of including synthesis in his set-up. This parallel increase in openness to sound synthesis and the order of action–sound separation in the instrument categories that the respondents represent could, of course, be a complete coincidence. However, it could also be indicative of a tendency among musicians in general that the action–sound categories to which they belong are an important factor in the forming of their musical approaches and preferences.

Ready-at-hand vs. present-at-hand

In Part I, we were introduced to Martin Heidegger's (1962) distinction between viewing a tool as ready-at-hand, exemplified by a carpenter who uses a hammer for its purpose without consciously thinking about the hammer itself, and as present-at-hand, as when the head falls off the hammer and the tool itself becomes the focus of the carpenter's attention and he sees the hammer in its true phenomenological light. Magnusson and Mendieta (2007) suggest that musicians working with digital instruments are more likely to experience these phenomenological breaks.

> In fact, the way we use a computer and digital instruments is a constant oscillation between these two modes of being ready-at-hand and present-at-hand. We forget ourselves in working with the tool for a while, but suddenly we have to open or save a file, retrieve a stored setting, switch between plug-ins or instruments, zoom into some details, open a new window, shake the mouse to find the cursor, plug in the power cable when the battery is low, kill a chat client when a 'buddy' suddenly calls in the middle of a session, etc. In this respect, many of the participants saw the computer as a distracting tool that did not lend itself to deep concentration (Magnusson and Mendieta, 2007, 5).

While it may be true that many computer musicians who also play acoustic instruments feel this way, I wonder if Magnusson and Mendieta's conclusion may be confusing several aspects of working with music. For one, we have seen that the divide between the roles of composer, performer and instrument maker is less clear when working with digital instruments (Freeman 2008). In fact, Magnusson and Mendieta mention this fact earlier in their paper. However, they don't seem to take this into account in the quote above. We could, for instance, imagine a composer sitting by the piano, alternating between trying out a theme on the instrument and writing down notes on a piece of paper, shaking his pen to get the ink flowing, shuffling between pages in the score to get an overview of the whole work while blocking a phone call from his agent because he forgot to switch off his phone before sitting down to work. This scenario is no different from the one Magnusson and Mendieta describes. The confusing fact is that the computer is more than merely a musical instrument, it is a tool for composition and music structuring, it is also a communication device and, as such, it harbors many potential distractions. The inability for some musicians to use the instrument in the mode of ready-at-hand for more sustained periods could be because they lack the routine compared to their acoustic instruments, or it could simply boil down to bad working habits.

The question of routine brings me to the second reason why I don't find Magnusson and Mendieta's conclusion particularly convincing. Any tool is present-at-hand when we are first introduced to it. Someone who has never seen a hammer before will look at it and try to figure out what it can be used for. We look for affordances. The more we get used to using a tool, the more it becomes ready-at-hand. Wallin's comment earlier about sitting up until 4 o'clock in the morning without consciously thinking about what he is doing shows that working with DMIs could be every bit as absorbing as working with acoustic instruments. Ratkje chooses not to work with sound synthesis because she realizes it would take her many years to be reach a level of expertise that would enable such a working mode. Her voice and the equipment she has learned to use are already mostly ready-at-hand. To me, it seems to be a matter of knowing the instrument well enough and obtaining optimal working conditions that allow the instrument to become ready-at-hand for sustained periods.

While it may be correct that musicians who work with computers tend to oscillate between the working modes of being ready-at-hand and present-at-hand with a higher frequency than when they play acoustic instruments, we should look to more than the nature of the instruments for the reason behind this inability to attain deep focus. I believe the main reason could be that a majority of the participants in Magnusson and Mendieta's survey are more experienced with their acoustic instruments than their computer-based tools. Based on the mean age of the participants (37 years) in their survey, and taking into account the fact that it has only been possible to work with music in real-time on personal computers for the past 15 years or so, I think there is every reason to believe that a majority of the survey's participants simply have many more years of experience with their acoustic instruments than with computer based music tools. If they had grown up playing computer-based music, the response would probably be very different. That is not to say that technical aspects do not get in the way when dealing with digital musical instruments; they do. Ratkje claims that she is forced to think more like a technician when dealing with electronics. Wallin says that it requires a "brainier" approach. The difference, however, does not seem to bother our participants to any considerable degree, and the gap seems to be closing as technology and its applications advances.

7.3 Performing With the Instrument

In this section, we are concerned with performance in a wide sense, meaning performing in front of an audience as well as experimenting with the instrument in a compositional or creational context.

Connecting with the audience when performing live

A live musical performance is a multimodal experience. Along with the sound of the music itself, inputs to the audience's other senses, and to the visual sense in particular, are powerful contributors to the way in which a performance is perceived.

When doing live improvisation, one of Barrett's rules for the past few years has been that she must perform together with an acoustic instrument in order for the audience to have a clear cause and effect relationship of the sound being made. She constantly samples the instrument in real-time so that there is an undeniable link between what she is doing on her computer and what the acoustic performer is doing.

> Otherwise, I could just be triggering pre-made samples. I could be miming… all sorts of things. For me, the point of it has to demonstrate, or touch people in the sense of the live event. […] I think that a live performance with an instrument is a multimedia experience from a listener's point of view. You use your eyes as much as you use your ears, and without this very direct link between the sound-making instrument, from the acoustic point of view, and the output of the computer, then I find that that link, or the purpose of having a visual performance, is broken.

Barrett points out that she spends most of her time writing acousmatic music, where the whole purpose is to remove the visual sense from the music in order to enhance the listening experience. In acousmatic concerts no performer is visible; the audience sits and listens to music coming from speakers. The contrast between her acousmatic concerts and her live improvisation performances shows that Barrett is keenly aware of how powerful the visual aspects of a performance can be. They can provide emphasis and context, as they do in her live improvisation performances, or they can potentially distract an audience when the focus should be purely on the sound.

Distractive visual elements in performance seem to be something several other of the participants are acutely aware of. Weak action-sound relations in particular are something they consciously avoid. Ratkje states that it is clearly a problem for a lot of people who work with electronic music live. “There’s the symptomatic example of a person sitting on stage staring at a laptop and nothing else going on in the room. I don’t see the point.” She explains that she has become increasingly aware of the disconnect that can arise between a performer’s actions and the resulting sound when using electronics. However, she doesn’t think this problem applies to her performance style.

> I think I’ve always moved quite naturally in relation to the sounds I am making. […] You can tell by looking at my body when I’m about to make an attack, or something that will be powerful. Or if something is going to be soft, that it will come creeping, in a way. You can see it in my posture. You can also see [these things] in a violinist or a pianist. It’s very observable. […] Using electronics is so new, though, so we haven’t developed the same archetypes for how to look when playing.

Ratkje believes the vocal elements of her performance are more accessible to those in her audience that are not trained musicians, while those that are musicians or interested in technology seem to value both her vocal and electronic performance equally.

> I do get the feeling that I’m reaching out to more people when using vocals. […] When using electronics I experience that the audience gets carried away more easily if I have something physical to play with, so that they can see that there is movement that corresponds with the sounds they are hearing. It’s often quite obvious, the way I play. I think I sometimes play quite simple just to make it clear. I make clear breaks and contrasts.

Ratkje expresses sympathy for the idea of acousmatic performances as an alternative to being on stage and performing operations on a computer that an audience cannot possibly relate to. “It seems more authentic to be standing behind a mixer out of view from the audience. Then they can just close their eyes and listen to the speakers instead.” Wallin expresses a similar view, also mirroring her thoughts about the visual aspects of performance. He describes the scenario of watching somebody on stage who is “looking like he’s checking his email” as completely uninteresting to him. He explains that if the music is good, it's better to just sit and listen to the speakers unless there is some coordination between what you see and what you hear. He stresses that this doesn't mean that everything he does on stage needs to be something that the audience can understand.

> In regards to the Controller Suit, it's still sort of enigmatic because it's not like I press a button and then there's a sound. It's a granular synthesis affair that is running its course, where I just guide it in different directions, to put it that way. So it's a bit mystical too, but that's also a part of the sort of enigma that I create around the suit. To begin with, I thought this might be a problem—that you press somewhere and it doesn't say 'ding'. There are some buttons that are sound triggers [...] and that's all that is needed, really, to make people understand, 'Oh, this is live! He's not just standing there and gesticulating along with something that is being played back.' So then you understand that it's live, and the rest is sort of enveloped in mystique, in a way.

Bugge shares the opinion that too many electronic artists do too little live. He explains that some artists might as well have just put on a CD. It's more playback than a performance, which he finds relatively uninteresting.

> I don't feel I have this problem. People who come to see me in concert can witness the whole process from me playing the piano to it being recorded and run through the computer until it becomes something else before I play the piano again and build a structure. [...] I think people find this fascinating.

Bugge's description of the cyclic process of playing something acoustically, digitizing and processing it before returning to the acoustic source for more material to play with is reminiscent of Barrett's approach when doing live improvisation. In Bugge's case there is more of an oscillation between the acoustic and digital domains, because he is doing everything himself. In Barrett's performances two separate performers play the acoustic and digital instruments continuously in parallel.

Based on what we now know about Nowitz's "sound dancing" approach, it should come as no surprise that he also sees visual elements as highly important in a performance situation.

> [...] When I go to a concert I always appreciate performers who are visible, meaning performers who make music also interesting for the eyes. [...] Our senses are so much related to the eyes, and if I watch a musical performance on stage and I cannot relate their movements to what they are actually creating, after a while I get kind of frustrated, in a sense, because then I could just listen to a CD at home… no need to go to a concert. So this theatrical visual aspect, I think, is very important to me. In German you say 'Das Auge hört mit'.

Roughly translated, this last German expression means *the eye listens along*, and it seems to sum up nicely the views presented above. Vinjar, however, points out that it is also interesting to raise questions about the relationships between action and sound that we are conditioned to expect. Using the electric guitar as an example, he deliberates on the fact that a playing a flageolet (producing an overtone) on a distorted electric guitar can yield very powerful screams, yet the action required to produce this effect is very minute. From the genres of rock and heavy metal, we are used to seeing guitarists theatrically emphasizing such effects, belying the fact that the actual action that produces the sound is invisible to the audience. To underscore his point, he compares the approach of Bill Frisell as opposed to Jimi Hendrix.

> Bill Frisell, if you've seen a video of him playing, [...] could be sitting there playing, you know, completely into it [...] and then all of a sudden there's a 'GAAAHHNNG!' A scream, you know, just because he moved his finger a little bit... completely controlled, obviously. [...] It's a whole different planet from, you know, Jimi Hendrix, who hits his guitar at the same time. What Frisell does is, sort of, to understate the action and get these extremely controlled sounds out of almost no movements at all. It's almost like he's sitting there with a pair of tweezers in a laboratory with a microscope and searching out these sounds. While a heavy metal guy jumps three meters up in the air and strikes a chord and gets exactly the same sound. And this mismatch that Frisell achieves, it creates something in the music that is vital.

Vinjar's comments are further testimony to the fact that what the audience sees or does not see is one of the most important factors in a live concert situation. Musical performers can command an audience either by theatrically emphasizing actions to add emotional weight to the performance, by understating actions to challenge the audience's expectations, or by withholding a visual appearance altogether in order to turn the focus to the sound. The large gap between action and sound in DMIs requires performers to make very conscious choices about how to establish a rapport with their audiences.

The threshold of control

One of the most interesting findings that emanated from this study was the fact that all of the respondents more or less unprompted brought up the issue of bringing the instrument to a point where entropy occurs—where control is lost and the results are accidental or non-deterministic in nature. The degree to which their comments concur is remarkable, and reveals a driving source behind their musicianship that is apparently unrelated to the genres to which they belong or the instruments they play.

In my interview with Barrett, I asked her if she wished her instrument would be better at picking up her intentions momentarily. I was caught off-guard her rebuttal.

> […] If my instrument responded to everything I wanted it to, I'd probably be writing very boring music, because we do what we know, and we know what we like. Something which is a bit of a struggle can actually yield very interesting results. Which does not necessarily mean everything is going to be chance, but there is an element of surprise needed to push yourself forward in a direction or find something which you just hadn't thought of before.

Vinjar speaks warmly of the often surprising and interesting results that occur when constraints are imposed either on the performer or the instrument itself. He explains that a good pianist can reinvent himself by, for instance, taping some of his fingers together, forcing him to adopt new playing techniques. Expectations are broken, and these breaches are interesting.

> These things are easy to achieve with algorithms. You can set off a process that sounds good […] and let it develop for a while. Then you change it a little by little in arbitrary ways until something happens, which you never would have thought of by using your intuition […]. It just pops up because it was a mistake, pure and simple. All these mistakes are interesting.

Vinjar explains that the joy of finding points at which an instrument starts producing unexpected sonic results applies to all instruments, but that it is easier to achieve with digital instruments. "It's easier to control the degree of non-control."

Nowitz also actively seeks out surprises, claiming that this is the ultimate goal of the improvisational process.

> In musical terms it's something you are controlling, and at the same time […] not controlling. This is where music gets really interesting, and it brings you to a whole new level. The first step, of course, is that you have to learn how to use your instrument. You have to learn your voice and you have to learn the piano, the guitar, and you have to learn to use electronic instruments, in order to get to these points. To get to these points, where control is necessary to get there, but once there it's not about control anymore.

Like Vinjar, Nowitz underscores that, although techniques vary and musicians deal with different media, the principle of controlling non-control applies to all instruments—the voice included.

Bugge seems to find electronics especially well suited for seeking out entropic sonic events. He flourishes when working in the perimeters of what the software programs can handle. He explains:

> The sounds and the possibilities that emerge then, I think they sound very exciting. This is exactly what makes it so different from the acoustic sound source. You can take a sound and turn it into something completely, completely different in real-time. Forcing the program to its limits creates very exciting results—art by accident.

Ratkje quickly learned that using her equipment in the "wrong" way would often produce exciting results. "I try doing things that aren't supposed work, because that's when a lot of nice things happen." The program Ratkje often uses is based on ImproSculpt, whose web site postulates the following:

> Most of the time, the instrument might be able to bring you surprises… bringing in a new musical element. You are never 100 % in control, it is more like you push things in a general direction, let it evolve, and then adjust the bits you do not like and refine the bits that already sound good.[37]

Again, we are reminded of the perspectives provided by all of the respondents in their comments about the attraction they feel toward ceding some control and allowing for non-deterministic occurrences to take the music in unexpected directions. Through years of practice, they have learned what it takes to bring the instrument to points where neither they nor the instrument is "in control".

The topic of entropy and control in instruments was also included in Magnusson and Mendieta's survey (2007: 5). Here, they were interested in finding out how people related to the non-deterministic nature of their instruments and if it differs whether the instrument is acoustic or digital. They had two trends of responses. The majority saw the accidental or entropic in acoustic instruments as something positive and inspirational, while typically regarding unpredictable events as wrong or "buggy" when they occur in digital instruments. "However, there was a strand of people that enjoyed and actively searched for such 'glitches' in software" (Magnusson and Mendieta 2007: 5). There is no doubt that the respondents in the current survey belong to this latter "strand of people". Again, Magnusson and Mendieta's findings show that, while they have collected data from a vast range of musicians, their findings are not necessarily representative of musicians that are experts at using DMIs. I see the discrepancy between the findings in their survey and this study as a further sign that there are very few musicians who can claim to be expert DMI performers.

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[37] Øyvind Brandtsegg: http://improsculpt.sourceforge.net/pmwiki/pmwiki.php

7.4 The Future

As a final contribution to the empirical findings in this survey, we will have a look at what kind of development the participants envision for DMIs and electronic music culture in the future, and what they see as major challenges for the field.

Commercial vs. custom-made/research DMIs

Many commercial manufacturers of musical hardware and software seem to have reached a point of stagnation in terms of innovation. They are faced with a conundrum; because of the infinite ways in which controllers and sound engines can be mapped, the best way to sell enough to justify mass production in the short term is to make their products as generic as possible. Their innovation consists in improved interfaces, design, ease of use and increased choices between factory presets. As music systems or components in music systems, however, the majority of these commercial products have little new to offer. Coming up with something radically new involves risk, and would most likely involve the targeting of niche markets instead of aiming broadly. The major manufacturers' unwillingness to take these risks has inevitably opened up for smaller vendors to fill this gap. Ableton Live seems to have struck a chord among musicians who tend to find the more generic products off-putting. It is widely used by DJs and composers who perform live. Controllers specially designed for Live have emerged on the back of this success.

Nonetheless, the fact remains that generic products saturate most of the commercial digital musical equipment market, and there is a growing trend for musicians to look elsewhere for more exciting hardware and software to work with. Using game controllers is increasingly popular, and programming software such as Max/MSP enables the development of patches completely custom-made for the context in which they are to be used. A research community consisting mainly of academics and musicians who develop their own DMIs has been on the rise for the past two decades, and it seems increasingly likely that major innovations in terms of complete systems (controllers and sound engines as functional entities) are more likely to emerge from these circles than from the commercial market. The problem so far, however, seems to be that the custom-made products are too specialized to be commercially marketable.

They are very often developed for a specific purpose, a particular piece of music or are custom-built for one artist. Thus, the reality is often that the developers and their immediate networks are the only ones who ever learn that these products exist.

An important question in my study was whether the participants see some sort of convergence of the commercial and user-defined DMI communities in the future. It was originally my view that such a scenario is what it would take to usher in truly innovative DMIs that can be standardized enough to be marketable on a commercial level. The status quo of the usage of commercial DMIs in popular music culture is that much of the musical material is planned and prepared before a live show. Research or user-developed DMIs are more often geared toward real-time performance, as some of the respondents exemplify. I was envisioning new instruments with the adaptability of research DMIs and the marketability of commercial DMIs. This could bring about, in my view, a much-needed shift in popular music culture, a shift that would turn the focus of live electronic music events to the spontaneity of the music-making process, where there is room for improvisation and unexpected musical events. However, the replies provided by the participants have made me aware of the fact they do not all necessarily see a convergence between commercial and custom-built DMIs as likely or even desirable.

Nowitz explains that the commercial industry is focusing very hard on ease-of-use. Using drag-and-drop principles, for instance, you could simply load a bossa nova beat and mix that with a bass line from another genre, and build grooves working in this manner.

> All these approaches […] are not very musical in my understanding. They are very result-oriented toward clichés and toward musical results we have known for ages. And there are no new ways in that sense. [On the other hand], all these non-commercial approaches and various specified instruments like the one I've built, they are so specified and so special that it is hard to imagine that these can be commercialized. […] Personally, I would not be interested at all. I might be interested in giving the instrument to somebody who has the same perspective or approach to music as me. There's so much philosophy and aesthetics already involved.

According to Barrett, we are now seeing standardization when it comes to the processor and chip that are used on the circuit board. However, she does not envision standardization in the way these basic components are configured, calibrated and used for musical purposes.

> […] A reason that there is this difference between the commercial-generic and the custom-made is because the people that do things custom-made are the curious people that who are always pushing to find something different. I mean that's what drives them. That's what's interesting for me as well, is when I build a controller or work with a very non-commercial set-up with sensors. It's because it's really interesting, it captures something which is fascinating, which is not what I find in commercial sensors. And as soon as that package I've made, if that became commercialized then it would probably be less interesting for me because everybody would be using it, and I'd be looking for something else which would give me something more interesting, or different. So I think there will always be a separation. Because of how we are as investigative artists.

Although Barrett dismisses the possibility of standardization of custom-made instruments, she also claims that she would stop using an instrument that she has built if it became standardized. The apparent dislike of the idea of one of her instruments becoming something that many musicians could use reveals a perspective at odds with my original outlook. I delved into this survey thinking it would be a positive development for DMIs and for DMI-related music to see the emergence of some more or less standard instruments that could have music styles or cultures associated with the instruments. This would not entail the cessation of experimentation for anyone interested in making new instruments, but it would make novel DMIs in general more available to very many people. I realize that the way I have worded my question may have been confusing. I might have asked if it is likely that we will see a higher degree of cross-fertilization between commercial and custom-made DMIs. Barrett's reply indicates that we are, indeed, likely to see ideas that have the potential for mass marketing being picked up by the commercial industry. The problem with such a scenario is that the commercial industry is set to make money on ideas developed by people who often may have little desire to partake in the process of commercializing their innovations. This also opens up a cesspool of patenting and copyright issues.

Ratkje envisions a lowering of the threshold for musicians to start making their own instruments, and she hopes a growing number of performers will incorporate digital tools in their live set-up, with an emphasis on real-time performance as opposed to triggering prepared material in a playback-like manner.

Bugge claims that we are already seeing a popularization of custom-made software on the Internet. For instance, there are a lot of Max programmers that make objects designed for specific purposes. These objects are either sold or made available for free download on the web. His reply indicates that he sees the Internet as the most important channel for making software innovations widely available, thus bypassing the more traditional commercial hardware industry.

Like Barrett, Vinjar thinks that the field of custom-made research DMIs will always be separate from the commercial industry. He explains that there will always be fields of specialized knowledge that few people have the qualifications to share. Once a piece of knowledge becomes universal, the focus will be shifted to other areas and new things will be developed. However, he believes that we will see standardization of many alternative controllers in the years to come, which will replace the MIDI keyboard as the most standard controller.

Wallin mentions that new instruments need to fulfill a certain amount of success criteria in order to achieve a commercial breakthrough. He uses the example of Reactable[38], which seems set for commercial success when it will be released as a commercial product. Reactable's design is truly eye-catching, and the interface is aesthetically pleasing and intuitive to work with (picture). Several performers can use the controller interface at once, enabling them to improvise using the same instrument. It seems that Reactable has the "it" factor that is necessary for commercial success. Renowned artists such as Björk have used it on tour, which is a huge promotional asset for the team behind the instrument. Although it is innovative in terms of control, Wallin explains, there is nothing truly groundbreaking about its functions. "It's nothing more than a good old patch synthesizer, only it looks very cool." Wallin's claim can be corroborated by referring to the Reactable web site:

> The way the Reactable works is deeply inspired by modular analogue synthesizers such as those developed by Bob Moog in the early 60s. Reactable's pucks represent the building blocks of electronic music, each one having a different functionality in sound generation or in effect processing. While in modular synthesizers one typically had to connect these different modules with patch cables in a complex and error-prone process, on the Reactable this is attained in a much easier and intuitive way, since connections between the pucks are managed automatically based on their types and affinities and on the proximity between them.[39]

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[38] A collaborative electronic music instrument with a tangible multi-touch interface developed by a team within the Music Technology Group at the Universitat Pompeu Fabra in Barcelona. http://www.reactable.com/

[39] Accessed 2009: http://www.reactable.com/reactable/

Wallin expresses surprise at how retrospective so many apparently new and alternative products turn out to be. Regardless of his ambivalence, the Reactable is a good example of a so-called research DMI turning into a commercial product. It shows that a convergence between the two fields can yield successful results. Despite the fact that the synthesizer contained within the Reactable is inspired by old patch synthesizers from the 60s, it will still be one of the most exciting and complete DMIs (as opposed to being marketed as a controller and/or a sound engine separately) made commercially available for a long time.

Figure 7.2. The Reactable.[40]

Conservatism and lack of conditioning

Several of the participants lament the conservatism permeating the public and educational spheres, and claim that development is partially crippled by a bias toward traditional instruments and musical styles.

Vinjar's main complaint is directed at the educational system, which he thinks is lagging seriously behind the times. Although music academies have recognized that music technology should have a place in their curriculum, their measures lack

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[40] Photo from http://www.reactable.com/reactable/

foresight, and the results suffer accordingly. He is dismayed by the music academies' lack of willingness to educate musicians to use technology in their work:

> Just look at how technology is used and plays a decisive role in all other domains. A physician that is unwilling to use a computer is unthinkable. A linguist unfamiliar with the right computer tools no longer exists. While in music, you can go through a long education, both as a composer and as a performer, without dealing with technology, modern technology, more or less. There is a slow development, but it's still extremely conservative.

Although digital technology by now permeates music culture, the music itself is still very focused on instrumental archetypes, which is something people can recognize and understand. Barrett attributes this to our cultural conditioning. We are brought up from infancy to understand acoustic instruments, she explains. The sound of a violin string being plucked is something we immediately can recognize. Barrett explains that we can be brought up to listen to sounds in a completely different way.

> […] There is the archetype of the plucked sound, which might not necessarily be a plucked violin string. It might be anything under tension being plucked. Then that understanding as a prototype is something we can also appreciate, and also connect to without it being alienating or abstract. […] The more we start working with sound on computers at school rather than necessarily having to play an acoustic instrument to get through your music course, the more the appreciation of the prototype of the pluck will be a non-alienating and a very natural listening process. I think this has already changed in the past twenty years, in a general sense of listening amongst younger people. But it's a slow process. I mean we're still brought up with violins and cellos and drums and pianos and wind instruments around us at school more than we are computers with sounds.

Ratkje is bemused by how many people tend to have an unnecessary respect for electronics. The fear of displaying a lack of knowledge seems to be stronger than the curiosity that drives the learning process. She tells of being met by utterances of awe, followed by prolonged silences, upon telling people that she performs live electronics. Journalists and fellow musicians who are unfamiliar with electronics also have some strange hang-ups in regards to the laptop. She explains.

> The laptop is the framework for the instrument; it is not the instrument itself. It depends what you have inside the laptop, right? […] Still, there is a sense that if you use a laptop you're 'that kind' of a musician. But […] that's just like saying that if you use a microphone then you're 'that kind' of a musician. But it completely depends on what you put into the microphone. […] It's pretty weird, really. The laptop is part of my set-up but it's other things that I'm making music with. It's not the laptop making the sounds either, and so I end up having to educate people how [the system] works.

The comments provided by the participants in this section shows that an important step in the development of DMIs and a surrounding music culture is stimulating a process of enlightenment about digital technology, how it can be applied in musical contexts and learning new ways of perceiving music.

Other challenges and possible improvements

Even for the survey's participants, who have worked with digital technology in music for a long time, it's difficult to see where the field is headed. We have only seen the tip of the iceberg in a revolution unfolding. To finalize this chapter about DMIs in the future, I have collected some of the respondents' comments about what challenges they feel need to be overcome, and what can be done to improve DMIs in the future.

Nowitz thinks that the extreme rate of development of digital technology, while very exciting for exploring musical possibilities, may simultaneously be the main reason why building traditions for DMI is virtually impossible at the time being. This point arose while we were discussing why it could be that large corporations such as Yamaha are so obsessed with making DMIs that are easy to learn and easy to use, when their acoustic instruments are quite the opposite:

> [Acoustic instruments] have a tradition already. [...] If these instruments didn't have a tradition, they wouldn't produce them anymore. These instruments you are talking about are the ones that have a cultural background, and a historical background. And they have been grown through centuries and have gone through different phases of evolution. Whereas the new devices, the new electronic devices, they are brand new right now. They are so new, and also the development of this area is so quick that maybe in ten years nobody will be interested in such an instrument that I've created. It will already be obsolete!

Several of the participants mentioned that there is a lot of ground to be gained in the design of controllers in order to enhance the expressivity and spontaneity of DMIs in a performance situation. However, as Barrett mentions, more accurate control, less latency and other increases in precision doesn't necessarily mean that it will be a better instrument, but it allows the user a greater choice. "It means that they *can* use the instrument to be slow, clumsy and with high latency, or they can choose it to be precisely expressive of their physical movements. It's not necessarily that one is more desirable than the other, it's that it allows the choice."

For Vinjar, the biggest stumbling block in the path of development is not the equipment itself, but the attitudes of many people who choose to work with digital technology in music.

> You have to take the instrument seriously. [A digital musical instrument] is not a short cut to anything. It takes more than ten years to play a violin well. If you had spent an equal amount of time learning technology, learning how to express yourself with it, then you would achieve a result as good [as with the violin]. I'm certain of this. […] Training is necessary. We need to see the development of musicians […] who learn how to play [these instruments].

This final point made by Vinjar could be seen in relation to Barrett's comments earlier about cultural conditioning. It seems Vinjar feels that many people are conditioned to expect digital instruments to make the process of music making easier. Digital technology can certainly help in performing many complicated tasks at speeds inconceivable to the human brain. However, if the music fails to excite an audience there is not much aesthetical value in the operation of these processes.

Chapter 8 – Conclusion

This chapter provides a summary of the thesis, compares the theoretical and empirical research presented in parts I and II, comments on the relevance of the findings, reflects on the research process and presents possible areas for future research.

8.1 Summary

The starting point for this thesis was a question about why the development of digital musical instruments for real-time performance seemingly is such a complicated undertaking. Several observations and personal experiences led me to the formulation of this research problem. Firstly, the realization that very few DMIs actually feature sounds that are performed in real-time was making me disillusioned in regards to the value of the live performance of electronic music in general, and I discovered that many people share this feeling. The inability to understand what many DMI performers actually do onstage seems to generate an element of distrust in the audience. Preliminary research led me to the understanding that these circumstances are not exclusively an issue of technicalities involved in the design of DMIs. Problems related to fundamental properties of human cognition and the lack of a cultural context in which the real-time performance of DMIs can flourish are important to address.

The three theory chapters (2, 3, 4) provided an overview of a number of topics that I deem relevant in understanding the challenges involved in developing DMIs for real-time performance. Chapter 2 was dedicated to a review of the different components, mapping strategies and communication protocols that constitute a DMI. Various types of sensors, controllers and sound engines were presented, and I concluded that an insight into all these areas of research are necessary in order to develop DMIs for real-time performance.

Chapter 3 presented the human cognitive system viewed from an *embodied* perspective. With roots in *ecological psychology* and supported by research in the field of *cognitive neuroscience*, this chapter showed how *embodied music cognition* may be beneficial when designing DMIs. Innate properties of the human cognitive system, such as perceptual grouping, perception–action coupling, memory structures and the functioning of affective states and processes all contribute to ways of experiencing music that may be important to keep in mind when designing DMIs.

Chapter 4 turned the focus toward how our view of music undergoes change as a result of technological advances, and I argued that aspects of our musical culture at the moment may be out of phase with the rapid technological development. A look at how some traditional roles in music is facing change served as signs that a cultural shift toward new paradigms may be in motion. Furthermore, a classification system based on the *order of separation* between action and sound in the performance of various instruments was presented: *incorporated, direct, mechanical, analog electronic* and *digital*. These categories formed the basis for the empirical study in Part II.

Chapters 5, 6 and 7 formed the empirical part of this thesis, which was based on interviews with six DMI performers/composers. In Chapter 5, I briefly discussed the methodological approach I used in the empirical study, and evaluated my progress in the qualitative research investigation through seven stages.

Chapter 6 was dedicated to a presentation of the musicians I interviewed for this empirical study. I think that an insight into the backgrounds of the various participants and an overview of their featured DMI set-up was necessary to provide a context for the subsequent chapter.

In Chapter 7, I presented an analysis of the findings based on transcriptions of the interviews with the participants in the empirical study. The findings were presented along the lines of some main themes that crystallized out of our conversations: *Developing the Instrument and with the Instrument, Operating in Different Domains, Performing with the Instrument* and *The Future*.

8.2 Comparison Between Theory and Empirical Findings

The theoretical part of this thesis was developed both before and after conducting the interviews that were my sources for the empirical study in Part II. The interviews provided me with important insights and made me aware of theoretical perspectives that I had not taken into account. Subsequent revisions of the theoretical part have been influenced by these new insights, and the theoretical and empirical parts of this thesis have been developed in tandem to certain extent. Nonetheless, I have in essence stuck with my original intention of an “A to B” presentation, where the theory is presented as preceding the empirical findings. Fortunately, the theoretical groundwork has proved to be quite solid—most of the theories and hypotheses in Part I is echoed to varying degrees in the empirical findings. In the following, I shall briefly draw comparisons between the theoretical and empirical material, chapter by chapter (1–4).

Chapter 1

Answers provided by the respondents proved that my research question and concerns regarding the perceived authenticity of real-time DMI performance were of a non-trivial nature. The respondents seem to have given these problems much thought, and were more than willing to share their experiences with me. They invest considerable effort and care in developing their instruments, and their performance styles are adapted to the instrument in ways that are intended to create a rapport with their audiences.

Chapter 2

The respondents revealed great knowledge about the different components of their DMIs, although the terminology they used in describing them varied. The most important term, digital musical instrument, is a scientific construct (cf. Miranda and Wanderley 2006). None of the respondents seemed familiar with the term, and used colloquial terms such as electronic instrument, electronics, computer, synthesizer, sampler, etc. This made comparisons difficult at times, and it made me realize that different usage of terms may be problematic both in arts and science.

Chapter 3

Many of the topics in this chapter were not discussed directly in the interviews, as I think their abstract nature would have created an unnecessary distance between the respondents and myself. Instead, I asked questions that could lead me to answers related to the cognitive aspects of musical experience. Unfortunately, my grasp on these topics at the time was not as firm a year ago as now, and therefore, this chapter is left standing as more isolated from the empirical findings than chapters 1, 2 and 4. However, several links can be made between answers provided by Natasha Barrett and Anders Vinjar to ecological perspectives. I think this is due the fact that they are electroacoustic composers who are inspired by Pierre Schaeffer (cf. *sound objects, reduced listening,* Chapter 3.1).

Chapter 4

There is a high degree of correlation between the theories presented in this chapter and the empirical findings. The respondents were keen to emphasize the cultural lag (cf. Ogburn, Chapter 4.1) and retrospective attitudes apparent in society, and expressed the belief that more knowledge about technology applied in music is bound to change music culture in the long run. My comparison between different instrument categories according to orders of separation showed that there may be substance to my hypothesis that different approaches to music are cultivated, depending on which of these categories of instruments one has experience with.

8.3 Relevance

The ideas presented in this thesis may be relevant in several fields. First and foremost, I hope that they can provide insights for musicians who use DMIs, or who are considering the use of DMIs to make music. My attempt has been to provide a compilation of research from this wide array of scientific fields in one publication, formulated in a coherent manner. I hope the fact that I have tested the theories with an empirical study among musicians who have many years' experience with DMIs is a valuable contribution.

Furthermore, the thesis could hopefully also be resourceful to non-music research communities. Many of the challenges DMI development are applicable to the field of human–computer interaction (HCI) in general, which draws upon research from many of the same scientific disciplines as I have in this thesis.

Finally, I hope the thesis may be a source of new ideas to the research community involved with the development of music technology. I hope that perspectives offered in Chapters 3 and 4, and the findings presented in Chapter 7 may provide valuable insights and inspiration for future development.

8.4 Reflections

Although I have some experience with music technology in the form of digital audio workstations and sound programming, I do not consider myself a DMI user. Therefore, the process of writing this thesis has taken the form of field research, where my goal has been to understand DMI development from the perspective of musicians who are experienced users of DMIs. It has been hard work, and I have often felt that my lack of knowledge has been problematic. Now that I have completed the process, however, I believe that my alternative perspective is an important contribution. I started out representing the majority of music audiences who have a hard time relating to DMI performers, and as such, my findings may serve as a potential introduction channel for anyone who are fascinated with music technology, but are reluctant to ask questions out of fear for being exposed as ignorant and clueless. I think that DMI performers must be patient in letting audiences catch on, and be aware that it may still take several years before the real-time performance of DMIs becomes normal.

8.5 Future Research

A notion that was a central part of the methodology in the empirical study, was the categorization of instruments according to the order of action–sound separation: *incorporated, direct, mechanical, analog electronic* and *digital*. My hypothesis that experience with instruments from different categories may cultivate different ways of experiencing music was tested, and I found that the answers showed tendencies that correlated with my hypothesis. I remain convinced that the order of action–sound separation in instruments can determine a musician's music cognition in fundamental ways. Based on the research presented in this thesis, I would like to briefly elaborate on this.

Evidence for perception–action coupling demonstrates that a contributing factor to the way in which we perceive the world is based on sensorimotor representations of experienced actions. In other words, individual experiences of actions in development may have a strong bearing on how one perceives the world. Cognitive metaphor theory posits that all cognition is based upon successive layers of metaphorical projection, starting at the sensorimotor level and up to the highest levels of cognition. The level of abstraction attained in cognition must depend on structures in long-term memory that aid metaphorical projection. For this, training is necessary. To me, it seems natural to assume that brain circuits involved in the training of the voice must be quite different than the brain circuits involved in training to learn how to play a guitar, piano, synthesizer, and so on. The level of abstraction, I believe, must increase in proportionality with the order of action–sound separation in the instrument.

It would be interesting to test this hypothesis by conducting brain scan research on musicians representing the different instrument categories. For my hypothesis to hold ground, brain scans would need to show a larger concentration of activity in the sensorimotor brain circuits of a singer singing than, for instance, of a pianist or a DMI performer playing their instrument. Perhaps such a discrepancy is observable also when these different musicians listen to music passively. If these tests turn out to strengthen the hypothesis, I would further hypothesize that most untrained music audiences probably have "musical minds" that are more similar to incorporated and direct musicians than to musicians that play instruments with higher orders of action–sound separation. This would explain the reason why vocal music is such a universal phenomenon.

The motivation behind formulating these research questions is essentially the same as what lead me to ask the main question in this thesis: Why is it so difficult to develop DMIs for real-time performance? I think that appreciating the real-time performance of instruments that are as abstract in nature as DMIs requires training. Both the DMI developer/performer and the audience, then, must work together in order to accomplish the task of making sensors make sense.

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Personal Communication: Interviews

The transcribed material is not attached to the thesis.

Anders Vinjar. March 12, 2009. 14 pages transcribed material.
Maja Ratkje. March 24, 2009. 13 pages transcribed material.
Bugge Wesseltoft. March 31, 2009. 9 pages transcribed material.
Natasha Barrett. April 3, 2009. 16 pages transcribed material.
Alex Nowitz. April 16, 2009. 13 pages transcribed material.
Rolf Wallin. May 19, 2009. 10 pages transcribed material.

Appendix A

Questions for the half-structured qualitative research interviews (in Norwegian).

Veiledende intervjuspørsmål

BAKGRUNN

Kan du kort fortelle litt om deg selv som musiker?
Hvilket eller hvilke instrumenter har du spilt opp gjennom årene?
Hva består ditt eller dine digitale instrumenter av? Altså: kontrollgrensesnitt, programvare, osv.
Hvorfor har du valgt akkurat dette oppsettet?
Hvem er målgrupper for musikken du lager og fremfører?
Har du en formell musikkutdannelse?
(Både ved ja og nei) Hvilke positive og negative aspekter ser du ved dette?

FORMIDLING

Hva er det du i hovedtrekk ønsker å formidle med musikken du lager og fremfører?
På hvilken ende av skalaen ligger hovedvekten av din musisering: på formidlingen av store vedvarende ideer eller fluktige emosjoner og følelser?
Vil du si at ditt instrument er bedre egnet enn andre til å formidle det ene eller det andre (store ideer vs. fluktige emosjoner/følelser)?
Hva slags spilleteknikker / fremføringsteknikker tar du i bruk for å gjøre formidlingen tydelig?
Oppstår det tilfeller der du skulle ønske at instrumentet ditt ”forstår deg” bedre? (Tilfeller der du skulle ønske at dine intensjoner kunne bli ”plukket opp” øyeblikkelig?)
Hva gjør du for å kompensere for dette bruddet mellom intensjon og resultat?
Hvis du føler at det du forsøker å formidle ikke oppfattes av publikum, ser du på det som en svakhet i instrumentets design, eller din egen fremføring?

KOMPOSISJON

Hvilke komposjonsmessige knep benytter du, og er disse knepene direkte relatert til ditt instrument?
Bruker du ditt instrument til å lage nye typer musikk?
Er et nytt og lite utviklet instrument lettere å finne opp nye typer musikk med?

UTVIKLING

I hvilken grad utvikler du selv ditt instrument?
Hva er typiske problemstillinger i utviklingsarbeidet?
Underviser du i ditt ”nye” instrument?

DIGITALE VS IKKE-DIGITALE INSTRUMENTER

Hva vil du si er hovedforskjellen i måten du tenker eller føler når du spiller på (ditt digitale musikkinstrument) og på (ditt ikke-digitale instrument)? Kan du gi noen eksempler?

Bruker du ulike instrumenter til å formidle ulike ting, eller er det snakk om ulike måter å formidle de samme tingene på?
Hvilket instrument foretrekker du å improvisere med?
Har du noen formening om publikum har lettere adgang til dine sinnstilstander (dine mentale representasjoner) med et instrument eller et annet?
Hva kan vi lære av tradisjonelle instrumenter i arbeidet videre med å utvikle digitale instrumenter?
Fremføring på akustiske instrumenter er ofte en balansegang mellom lineær kontroll og ikke-lineær "lek". Finner du noe tilsvarende i digitale musikkinstrumenter?
Sampling vs. synthesizing

BEVEGELSE-LYD

Hvis du tenker på avstanden mellom dine bevegelser og lydkilden, kan du komme på ting du gjør i fremføringen som gjør at publikum opplever forholdet mellom deg og lyden som naturlig?
Hva gjør du for å oppnå maksimal ekspressivitet, som også kan oppleves av publikum?
Når et publikum ser en utøver spille et akustisk instrument, opplever de fleste et svært intuitivt forhold mellom utøverens bevegelser (f.eks. plukking av en streng) og den resulterende lyden. Selv når utøveren ikke er synlig, f.eks. hvis man lytter til en CD, vil denne lyden på basis av personlig erfaring oppleves så naturlig at man kan se for seg bevegelsen ved å høre på lyden. Med digitale instrumenter, er forholdet mellom bevegelse og lyd ikke gitt, noe som kan virke fremmedgjørende for noen. Er det virkelig nødvendig at et publikum forstår hva utøveren gjør for at musikken skal oppleves som levende?

DIGITALE MUSIKKINSTRUMENTER I FREMTIDEN

Vi ser en tendens til at digitale musikkinstrumenter fordeler seg inn i to hovedgrupper: kommersielt produserte, generiske og vanligvis MIDI-baserte instrumenter som er lette å bruke, og spesialiserte, brukerutviklede og gjerne OSC-baserte instrumenter som krever innsikt i programmering og kjennskap til lydbehandling. Ser du for deg at disse gruppene kan nærme seg hverandre, og at vi i fremtiden kan se en standardisering av mer sofistikerte instrumenter som likevel ikke krever at utøveren må forstå programmeringen som ligger til grunn for instrumentets funksjoner?
Et utbredt syn blant musikere så vel som musikkpublikumet generelt er at digitale musikkinstrumenter er mindre ekspressive enn ikke-digitale instrumenter (spesielt akustiske), eller at musikk fremført på digitale instrumenter er mindre tilgjenglig for publikum. Hva tror du er årsaken til at mange har denne oppfatningen?
Hva skal til for å bedre ekspressiviteten og spontaniteten til digitale musikkinstrumenter?
Hvilke forbedringer ser du for deg for fremtidens digitale musikkinstrumenter?

AVSLUTNINGSVIS

Hva legger du i arbeidstittelen *Making Sensors Make Sense*?
Diskusjon / kommentarer
Spørsmål du ville ha stilt hvis du var meg?

Appendix B

The introduction to the project sent out as attachments to the invitation emails to each respondent.

Making Sensors Make Sense
A qualitative survey among performers of digital musical instruments

Dear participant,

I am a master's student in musicology at the University of Oslo. In my master's thesis, which has the working title Making Sensors Make Sense, I am interested in uncovering the relation between type of instrument and the performer's repertoire of playing and composition techniques in musical performance. My vantage point is the field of music technology – more specifically the field of research that is working with the development of new digital musical instruments (DMI).

Digital music technology has become ubiquitous. However, it is noteworthy that the development largely has been focused around signal processing and composition, and to a much smaller extent around real time music performance. For example, we have an endless amount of digital tools that can be used for sound synthesis, recording, playback, effect making, arranging mixing, mastering, etc. The musical content, on the other hand, is in most cases based on non-digital (analog / acoustic) instruments. Considering that the digital age still is in its infant stages, we will without a doubt see an increase in the amount of musicians who use digital musical instruments when performing, but a widely held view at the moment, both among musicians and their audiences, is that digital musical instruments are less expressive than non-digital instruments. There lies a challenge in overcoming these prejudices and providing for a broad development of both digital musical instruments and an updated understanding of music.

With my project, I wish to take a few steps back and view the development of digital musical instruments in a broader developmental perspective. Different instruments have a varying degree of separation between the performer's actions (input) and the sounding result of these actions (output). Throughout music history, new types of instruments have emerged that have taken this separation one step further and led to the introduction of new paradigms in composition and performance. I have divided the degrees of separation into six categories:

1. Incorporated: The musical instrument is the performer's body, and the separation between action and the sounding result is incorporated in a biological entity. The voice is the most obvious example of an instrument in this category. Whistling, snapping and clapping also belong in this category.

2. Direct: The performer is in direct contact with the sound unit(s) and causes vibrations either by directly touching or by using a tool (bows, sticks, picks, etc.). Most acoustic instruments fall into this category.

3. Mechanical: The performer triggers mechanical processes that result in the vibrations of the sound unit(s). Keyboard instruments, such as the piano or organ, and other musical instruments that have mechanical links, belong to this category.

4. Electric: The performer produces sounds that are picked up by electromagnetic transducers (pick-ups) and amplified through one or several speakers. In this category, I exclude acoustic instruments where the sound of the whole instrument, such as the strings and the sounding board of a violin, is picked up by microphones and amplified without added effects. Examples of electric instruments are the electric guitar or clavinet.

5. Electronic: The instrument consists of a controller interface on which the performer plays, and a sound generator that bases itself on electrical signals from the controller. This group includes early electronic instruments such as the Theremin, the Hammond organ and analog synthesizers and sequencers.

6. Digital: As with electronic instruments, digital instruments consist of a controller unit and a sound generator, but the performer controls digital representations instead of electrical signals. Both units are independent modules related to each other by mapping strategies. There are many examples of digital instruments, but few standards. Examples are digital synthesizers, samplers and sequencers. It has become common to control using a laptop.

The development of musical instruments and musical paradigms has gone hand in hand throughout music history. The demand for new forms of expression has led to the experimentation with new instruments, new types of instruments have made performers and composers develop particular techniques and music systems, and when possibilities within these musical paradigms have reached a point of saturation, the demand for new forms of expression yet arises. This is a continual process, but we can see clear “quantum leaps” in music history, which I think can be ascribed to these mentioned steps in separation.

New forms of expression often harvest a certain degree of antipathy, both because the form of expression is insufficiently developed in the beginning, and because it takes time for people to develop an understanding of what is being conveyed. In my opinion, this antipathy is what becomes new musical paradigms’ “trial by fire”. It is not sufficient for a musical instrument to make interesting sounds; new modes of expression that can place these sounds in appropriate contexts must be developed. This entails radical thinking in musical expressions, in ways to apply musical instruments and in the design of the instruments.

By interviewing you and other musicians that have experience with both digital and non-digital musical instruments, I hope to be able to gain insights into the status quo in the development and use of digital musical instruments, seen from the perspective outlined above. I am especially interested in finding out what is the intended communication when using instruments in the various categories, and the relation between mental representations, controller actions and sound.

The interview is based on voluntary participation, and I will use audio recordings and notes from the interview in my further work on the thesis. The answers can be made anonymous if preferable, and it is possible to withdraw from the project at any time until the results are published. The master's thesis will be completed in August 2009 at the latest. The interview will take approximately 1 hour. The recordings and notes from the interview will be destroyed at the end of the project. For more information about the project, please contact me by email sirnotto@yahoo.co.uk or cell phone (+47) 98 88 26 13. My supervisor is Alexander Refsum Jensenius, email a.r.jensenius@imv.uio.no. I would greatly appreciate your participation in this survey.

The project is reported to the Privacy Ombudsman for Research, Norsk samfunnsvitenskapelige datatjeneste AS.

Best regards,

Notto Johannes Thelle
Master's student, Institute of musicology, The Faculty of Humanities, University of Oslo, Norway
Declaration of consent
I have received information about the survey Making Sensors Make Sense and wish to participate.
Participant's name: ___________________________________ Signature:
_____________________________ Date: ______________________________