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GESTURE, SOUND, and the ALGORITHM

Performative approaches to the revealing of chance process in material modulation

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Résumé

Cette thèse de maîtrise traite du processus créatif et de la recherche qui y est associée afin de produire deux performances en direct dans le domaine de la musique électroacoustique. À l'aide de ces deux œuvres, mon intention était de concevoir une pratique artistique qui réunit plusieurs modes autour de la gestuelle et du son, influencée par des algorithmes.

Une tentative approfondie d'extraire un processus de composition à partir des réactions de la matière en vibration englobe une grande partie de la recherche. Cette recherche découle de ma transition d'une pratique artistique basée sur la *représentation* (soucieuse des haut-parleurs, manettes et boutons) vers une pratique imprégnée par la performance (soucieuse de la transformation continuelle du son en relation avec les modulations de la matière). Tout au long de cette recherche, j'ai mené un examen approfondi des rythmes au-delà de la pure mesure de leurs expressions musicales, pour considérer les nombreuses notions du rythme qui se dévoilent dans les interactions quotidiennes de l'expérience vécue. Les micro-rythmes perçus par l'oreille comme des textures, les gestes répétitifs perçus par l'œil comme un mouvement linéaire et les rythmes observés lors de circonstances sociales communes, comme la cadence de la conversation sont, parmi les caractéristiques du rythme qui ont suscité mon intérêt. Le tout se situe dans un récit historique éclairé qui étudie l'influence de l'algorithme et de la matière tout au long de la musique et de l'art sonore du XXe siècle.

La recherche conceptuelle est enrichie par des expériences exhaustives en composition algorithmique, analyse gestuelle et modélisation gestuelle. Dans chacun de ces domaines, bien que soutenue par des lectures fondamentales en philosophie et en art, une approche primaire de la création s'est faite dans un processus « réfléchir-en-faisant » qui ont généré de nombreuses expériences tant avec la matière physique qu'avec la conception d'instruments numériques. Au-delà de la création des performances qui constituent la base des résultats de cette recherche, un vaste ensemble d'outils interopérables d'analyse gestuelle en temps réel, de modélisation, de composition algorithmique et de traitement du son a été développé et publié pour l'environnement Max/MSP.

Mot clés: performance électroacoustique, composition algorithmique, cartographie gestuelle, analyse des gestes, conception interactive, calcul matériel, matière topologique

Abstract

This master's thesis concerns the creative process and related research for the production of two live performances in the domain of electroacoustic music. Across the creation of the two works, my intention has been to develop a unified multi-modal gesture, sound, and algorithm influenced performance practise.

Encompassing the largest portion of the research is an earnest attempt to derive compositional process from the behavior of vibrating matter. This research is precipitated by my movement from an artistic practice based on *representation* (concerned with speakers, knobs, and buttons) towards a practice steeped in *performance* (concerned with the continuous transformation of sound correlated to material modulation). Across this research, an in-depth investigation was conducted into rhythms beyond their purely metric musical manifestations, and into the numerous alternative notions of rhythm which are revealed through daily interactions and lived experience. Rhythmic artifacts of interest have included micro-rhythms perceived by the ear as textures, repetitive gestures perceived by the eye as linear motion, and rhythms observed in ordinary social situations such as the cadence of conversation. This is all situated within an informed historical narrative which considers the influence of the algorithm and material primarily across 20th century music and sound art.

The conceptual research is augmented by extensive experiments in algorithmic composition, gesture analysis, and gesture mapping. In each of these areas, though tied to fundamental readings in philosophy and art, a primary approach to creation has been *thinking-through-making*, which has led to extensive experimentation with both physical materials and digital instrument design**.** Beyond the performance creations which form the basis of this research output, a large set of interoperable tools for real-time gesture analysis, mapping, algorithmic composition, and sound processing was developed and published for the Max/MSP environment.

Keywords: Electroacoustic performance, algorithmic composition, gesture mapping, gesture analysis, interactive design, material computation, topological matter.

List of figures

1. Introduction

Through the realisation of a composition practice which attempts to unify gesture, sound, and algorithmic composition, this research-creation project seeks to reveal musical processes in the physical modulation of matter. Following the development of a material focussed performance practice, I endeavour to construct defined methods for which compositional process can be derived from everyday gestures.

Two performance works have resulted from this line of inquiry**:** 1) *Coil Cascade*, a twenty-minute performance for springs suspended in space that are scraped, stretched and struck; 2) *Spiel,* a performance for prepared mouth, where a performer is entirely unable to speak with her own voice. She needs to collect voices and sounds from the surrounding environment in order to express herself back to the audience. Through extensive application of real-time sensors, gesture acquisition, and gesture mapping techniques these works broadly serve as studies on rhythm in its many alternative forms.

Across the following six chapters, the research and working methods involved in creation of the aforementioned works will be exposed and deeply analysed. In Chapter 2, I will give an overview of the conceptual background, including my efforts to discover rhythm in everyday situations (in conversation, and in spring motion), and my movement across the last four years from a practice based on *representation* to a practice steeped in *material performance*. In Chapter 3, I will provide a background of the relevance of the algorithm and the material in music, to situate the presented works in their historical context and milieu. In Chapter 4, I give an overview of the relevance of gesture to my performances, and the inspirations and approaches to gesture mapping for both. In Chapters 5 and 6, I will fully describe the concepts and approaches explored across the creation of both *Coil Cascade* and *Spiel*. In the concluding Chapter 7, I will briefly outline two future projects I intend to pursue, provide a critical overview of the two performances, and review the changes I still intend to make.

2. Conceptual background: rhythm, representation and material performance

In *Coil Cascade*, sound is continuously shaped as it undulates to harmonic and inharmonic spring motion. In *Spiel*, I reveal the cadence of conversation and test the capacity for physical formant inflections to process sound and induce auditory hallucination.

This approach to studying rhythm not exclusively from a musical point of view, but in its alternative biological, psychological, and social forms has been heavily borrowed from 20th century Marxist philosopher Henri Lefebvres' writings in *Elements of Rhythmanalysis* (1992/2016**)** and elsewhere. Lefebvre's studies look beyond their mere metric manifestations and the musical connotations that derive from those, rather his work casts a wide lens towards the numerous interpretations of rhythm which are revealed through daily interactions and lived experience. Across this writing, it will be revealed that I do not intend to state that I have concretely grasped what rhythm is in essence, merely that through creation of these two performances that I have begun to arrive somewhere *closer* towards understanding that essence.

Lefebvre underscores that "everywhere there is interaction between a place, a time, and an expenditure of energy, there is rhythm" (Lefebvre, 1992/2016, p. 25). Lefebvre finds rhythm in any experience of repetitive action, difference, and gesture, and likewise in any birth, growth, peak, decline, and end. Rhythm absorbs us into a multifaceted relationship between the perception of the present moment, the memory of the moment which just passed, and the prospect of the moment to come. Rhythm, as performed biologically by the sampling rate of the eye, allows us to separate the visual experience of the world into a kind of sensory trajectory, reducing the immense amount of information received by our sensory system down to an ordered set of explicit intervals. But Lefebvre argues that rhythm exists beyond both time and sensory input, rhythm operates as a kind of tangible force or process of revealing. I have referred to Lefebvre's work across the creation of my compositions as I have sought to identify non-metric manifestations of rhythm in everyday situations including in conversation (in *Spiel*), and in physical-mechanical processes (in *Coil Cascade*).

Utilizing sensor driven gesture analysis techniques mapped to real-time algorithmic composition systems, I investigate how chance procedures can enrich the stochastic nature of matter itself, and following my study of Lefebvre, render various kinds of hidden (non-metric) rhythms appreciable to the human sensory faculties. I have delved into the emergent field of material computation and extended my research into the areas of physical science to develop compositional relationships correlating to material qualities like strength, plasticity, elasticity, and conductivity. In parallel, I have developed defined methods for connecting these traits with algorithmic and generative compositional systems. In so doing, I study the phenomenon of material movement across time as potential compositional process, stripped from associated technological abstractions like interfaces, knobs, buttons, and screens.

From representation to performance

In the creation of my two compositions, I attempt to move from my previous compositional practice which revolved around *representations*, towards an embodied performative practice. This encompassed a global shift of perspective in my practice: from working primarily with non-real-time numeric systems, to real-time performance where numeric models are treated as a material to be continuously unfolded and modulated at different scales across time.

This progression in my own practice is widely mirrored across the history of 20th and 21st century composition, electronic and otherwise. Prior to the 20th century, music was mostly represented as individual notated elements on paper arranged in chronological order. This method of representation was capable or encoding many (but not all) features of a musical composition. Prior to the advent of recorded sound, and even up until the invention of magnetic tape, it was impossible to permanently encode every single nuance of a composition. Many individual elements were left to the discretion of the performer to envisage the composer's intention, leaving an infinite number of possible permutations for a given composition (Wei, 2013, p. 23). Later in the 20th century, John Cage would arrive and present the concept of using notation merely as a descriptor of process (see more in Chapter 3.1). Instead of inscribing every individual element of a performance onto paper, Cage's work post-1950 looked towards notating at the level of the meta-event, a list of directions to be undertaken by a performer in order to arrange a given set of elements into a score that could be performed. Here, there is evidence of a progression from music written prior to WWII which was widely scripted moment by moment, to performances like those by Cage rejecting the notion of deterministic linear scores existing prior to performance (p. 29).

With the entrance of the computer revolution, representation as it exists in numerical models could now be presented as a simulation, or as infinite permutations of visualized (and sonorized) data. With the vast increase in processor speeds across the last 20 years, it has become possible and even highly practical to perform advanced numerical operations in real-time in a way which previously could only be performed off-line by powerful mainframe systems. This change in the discipline of electroacoustic and computer music, from rendering music or processes to tape, to having the ability to model the sound in real-time based on variable inputs from live sensors tracking physical systems in space has had a significant impact in the field. Wei argues in *Poiesis and Enchantment in Topological Matter* (2013) that "this enables, but does not guarantee, a 'performative turn' in the domain of computer music**"** (Wei, 2013, p. 49). Of course, a fast frequency computer processor is only one component necessary in the practice of augmenting performative systems with computation, rather in order to be effective the entire operation must exhibit a great deal of "resolution, range, syntactic density completeness, nuance, [and] connotative potential (poetry)" (p. 50).

From digital models to material computation

In the creation of my research-creation works, I employ a *topological*[1] framework, which is elemental to my compositional process in the aforementioned works. To consider the modulation of material across time is to likewise discuss the *topological figure*, defined as a deformation of a geometric shape across time, it is "the continuous transformation of one geometrical figure into another" (Massumi, 2002, 134). In *Parables for the Virtual* (2002), Brian Massumi describes the *topological figure* as follows. Consider an imaginary flexible cylinder. One can squish the ends of the cylinder into each other, forming a closed tube. Imagine stretching the cylinder so that the diameter is consistent across the whole tube, and then pull one end of the tube into the other, the resulting physical transformation of the cylinder is equivalent to a wheel. One could then twist and pull at the wheel, and tie any number of intricate knots. One could roll the flexible knots on the floor, repeatedly applying pressure to completely flatten the material. Every

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[1] Topology is a branch of mathematics which deals with properties of geometric configurations which remain unchanged across repeated deformations (Merriam-Webster).

possible geometric shape that can be created in this fashion are merely transformations of the same *topological figure* (p. 134). I employ a topological framework in these compositional studies by exploiting materials which are capable of many kinds of deformations and physical distortions. Both the spring and the mouth are capable of subtle deformations of form, and in performance are analyzed across time by multiple sensors. Data received from sensors attached to moving matter is used to create new sounds, textures, and musical structures which precisely model continuous deformations of the topological figure across time.

The invention of photography, and later experiments in moving images resulted in some of the earliest examples of an intrinsic attempt to capture the topological image. By cutting up slices of motion, placing them one after another in time, and scrolling through them at a fast-enough rate, a gestural impression could be presented to the audience. In one of the earliest examples of precise temporal movement tracking, French physiologist Étienne-Jules Marey went searching for the various "parameters of movement, its amplitudes, periods, phases, and fluctuations" (Salter, 2010, 222) and by doing so rejected previous movement studies which relied on observation and human sensory information. Marey sought a way to transcribe human movement utilizing mechanical instruments and developed systems relying on sensors, transducers, and inscription mechanisms to render the internal fluctuations of bodily fluids and muscle movements. He then went on to invent techniques for precisely recording external body movement, moving towards electro-optical transcription systems as opposed to his previous mechanical creations. Marey's thorough study of movement performed in the domain of photography, is highly related to my own attempt to map sound in real-time to the physical modulation of matter, and as will be developed further, maintains significant similarities to the two described compositional studies.

As Sha Xin Wei argues in *Sound Design as Human Matter Interaction*, "under the fiction of the digital there is always the hiss of electrons and of matter-energy fields in physical, even quantum mechanical transmutation" (Wei et al., 2013, p. 2). When one considers a traditional computation device (screen and box) there is a tendency to imagine that what is displayed on the screen exists outside of the physical (or at least the analog) world, when in fact the materials used to construct such a device are not extraordinarily different than those which otherwise surround us. Where does one draw the line between the analog and the digital, the natural and the artificial, the physical and the immaterial? For the purpose of this research, I do not feign knowing a true answer to these questions, and nor do I expect the course towards resolving them will be well defined, however through the creation of my aforementioned compositional works I have endeavoured to exploit the edges of these queries and distill a sense of their substance. My approaches in creating computationally active materials which are perceived primarily as physical material objects are detailed in Chapters 5.3.2 and 6.1.1.

At this point, it may be clear the global view that my practice now subscribes to: that the physical and digital world are intrinsically linked, rather than separate worlds where one exists as the real-thing and the other as a facsimile of the real. Indeed, beyond the mouth and coiled spring, there are many kinds of matter which contain complex structures and unique dynamic properties. It is my intention to study materials present in the physical environment as potential decision-making systems, in the context of real-time performance and algorithmic composition, which relates directly to the developing field of material computation. As explained by Susan Stepney in her article *The Neglected Pillar of Material Computation* (2008), the stated goal of the material computationalist is to spur matter to make calculations in order to solve human questions (Stepney, 2008, p. 1158). In both *Coil Cascade* and *Spiel* I have endeavoured to exploit the potential of traditional computational processing by augmenting it with the physical properties of material substrates. By so doing, I intend to challenge the concept of reality which is derived solely from information received by the sum of our sensory faculties and, as stated by Ikoniadou, “bring forth instead the potency of a speculative-digitality that is inseparable from computation” (Ikoniadou, 2014, p. 89).

3. Historical background of algorithm and material in music

Across my practice, the algorithm has served as a fundamental way to both conceptually frame and construct my compositional work. What has seemed particularly interesting to me is the capacity for the algorithm to function in real time, for it to be connected to diverse streams of information, and for it to add its own sense of agency and uncertainty to the result of a composition as it progresses across time. In the two works presented in this paper, I have attempted to move a step further, and derive some sort of algorithmic process from the physical movement of matter. I attempt to find musical behaviour in objects and map that behavior to compositional and computational algorithms which are designed to enhance the physical movement but not fundamentally alter its form.

In considering the potential of the algorithm to influence the outcome of a compositional work, it is relevant to consider the broader historical context of the algorithm in music, which this chapter will develop. In this section, six approaches will be discussed: that of Pythagoras, to clarify the breadth of historical context; of Wolfgang Amadeus Mozart, for an early example of chance-based compositional process and the relevance of chance in the presented works; of John Cage, for his extensive work in indeterminant composition, and its relevance to the works at hand; of Iannis Xenakis, in his unique combination of acoustic and sine wave recordings as re-organised by statistical analysis, which bears many similarities to my working methods; of David Cope, for an entirely different perspective focussed on neural networks and recombinance, of which a form has been implemented in *Coil Cascade*; and lastly of Tom Johnson, for his paper and pen techniques for self-similar melodies which are highly influential to the composition of *Coil Cascade* and my practice in general across the last seven years.

3.1. Historical context of the algorithm in music

In the writings of Pythagoras.

The term 'algorithmic composition' refers to the technique of using a formal process to produce music, with a varying amount of human intervention (Alpern, 1995). With this definition, one can see that the use of process and instruction in music dates to as far back as the ancient Greeks. Grout and Palisca (1996) write that "The word *music* had a much wider meaning to the Greeks than it has to us. In the teachings of Pythagoras and his followers, music was inseparable from numbers, which were thought to be the key to the whole spiritual and physical universe" (as cited in Maurer, 1999).

In Mozart's Musikalisches Wuerfelspiel.

In the classical era, one strong example of compositional work determined by algorithm or chance, exists (presumably) in the work of Wolfgang Amadeus Mozart (1756-1791). Though there is some debate amongst music historians whether the piece in question *Musikalisches Wurfelspiel* (Musical Dice Game) was truly composed by Mozart (Zaslaw, 2005, p. 227), it nonetheless serves as an interesting point of reflection. Composed in the style of a Viennese minuet, the work was highly innovative in its time—where for every 16 bars of music the audience was offered multiple choices determined by dice rolling which determined the final compositional outcome. For the 8th and 16th bars, the audience is given two choices, while for every other bar in the piece, the audience is given 11 options (Ruttkay, 1997, p. 18).

The intention was to offer the performer or audience the ability to generate a great variety of melodic variations from a selection of stock compositional fragments which consisted of individual pre-scored bars of music. Mozart went to considerable lengths to ensure that for any chance-based selection, the melodic outcome would be an elegant minuet, which satisfied all of the harmonic and compositional necessities of the Vienesse minuet style of the era. Though it was possible that some resulting melodic constructions would be less interesting, due to stochastic repetition of bar fragments, the fact that interesting compositions could be assembled at all from such a limited selection of material and by such simple means (the chance of the die) was in itself evidence of the composer's virtuosity (Ruttkay, 1997, p. 18).

Musikalisches Wurfelspiel was first published in Berlin and Amsterdam in 1793 by J.J. Hummel, and later republished in many distinct forms. The original manuscript for the work by Mozart has never been discovered, and for a long time his attribution to the work was never disputed by musicologists. In each publication of the work, the audience or performer was demanded to use two dice to assemble the composition, which was organized as follows: toss the two dice, and use the sum of those two values, subtracting one to arrive at a value between one and 11 which is used to determine the specific fragment number to employ at any given moment in the minuet (Ruttkay, 1997, p. 18).

Chance procedure in the work of John Cage.

By the early 1940's, John Cage was already exploring the potential of using numerical charts and systems to control elements in his compositions. For example, in some of his early percussion works he used a numerical series to modulate the density of events. At this time, his style still allowed him great freedom in the resulting organization and construction of consecutive events. In 1951, John Cage wrote the *Music of Changes*, and he was moving towards using chance procedures to globally control the orchestration of a piece, rather than simply defining individual elements. In *Music of Changes*, the sound material selected was determined both systematically and by subjective aesthetic selection. While the structure of the composition was determined by the square root formula, the meter and individual pitch choices were relegated to chance determination. Cage's work during this period was a hybrid of chance and notated strictly deterministic behavior, but the unpredictable was beginning to take hold of his compositional process (Gena and Brent, 1982, p. 84-5).

While Cage's early 1950's pieces consisted of conventional scores where pitches derived by chance were notated in strict order, by 1957 he was approaching composition from a refreshed perspective. Beginning with *Concert for Piano and Orchestra* in 1957, Cage moved to writing performances in which all individual elements would be consigned to chance (Gena and Brent, 1982, p. 86). For example, the score of the aforementioned piece consists of 63 pages to be performed in whole or in part for any duration, with any size of performance group (solo, chamber, symphony, etc.) Each part was written with a system whereby space is organized relative to time, with time decided by the musician and modulated in performance by the conductor. The piano part consists of 84 different kinds of notation spread cross 63 pages, where a pianist can choose to play the written material in part or whole, by selecting any individual part and arranging them in any order. Cage further implicates indeterminate procedure in the scored parts by utilizing the imperfections of the paper upon which they were written. (John Cage Complete Works)

Cage's combination of pre-composed material, collage, and conventional notation would be a major focus in his compositional work through much of the following two decades (Gena and Brent, 1982, 86-7). As will be discussed further, I have taken considerable inspiration from his post-1950's compositions. A further extrapolation of Cage's process is provided in Chapter 3.2, through a description of his workinng process in the creation of *Reunion* (music for chess) with Marcel Duchamp.

David Cope and computational creativity.

In 1987, Cope presented his first paper on *Experiments in Musical Intelligence* at the International Computer Music Conference (ICMC) (Cope, 2005, p. 86). This software, like many of Copes earlier computational composition systems, were reliant on recombinance: "a method for producing new forms of data by recombing existing data into new logical orders" (Cope, 2005, p. 88). He spoke for only 10 minutes on the design and theory behind his software, and afterwards played back a few short passages from the recorded result. These recordings included five measures of music composed by his recombinant computer system in the simulated styles of Bach, Beethoven, Bartók, and Brahms. When the tape finished playing, the audience sat stunned in silence, offering neither questions nor applause. In presenting his work across the next few years, Cope would find a similar experience, which he would later attribute to "the music confused and dislocated the audience, since they had no previous comparable experience" (p. 86).

Cope argues that recombinance is a key technique for producing music highly similar to, but new and as yet unheard, as he finds that in all kinds of music composition there exists a kind of rule set for creating diverse musical phrases which are still closely related, as inter-connected replications of the phrase itself (Cope, 2005, p. 86). After 2003, Cope shelved his *Experiments in Musical Intelligence* project (deleting his whole database in the process) and looked to move beyond devising new compositions in historical musical styles. His current work looks at combining his previous techniques with integrated association networks (neural networks), first fully realised with his *Emily Howell* software, which he seeks to "present new music representing the evolution of a new *creative entity*" (p. 362-74).

Compositional method of Tom Johnson.

Tom Johnson is an American composer, based in Paris since 1983. Known for his musical compositions and operas rooted in minimalism, his compositional style encompasses a limited set of materials, simple structures, and reduced sets of scales which are usually organised by logical systems, mathematical formulas, or permutations thereof (Editions 75, 2018).

One of Johnson's early successful works, *The Four Note Opera* (1972), is indicative of a compositional style he would continue to pursue through present day. The piece functions as a kind of theatrical parody on the operatic form, selecting the more obvious tropes of the form and pushing them to the front of the work in a satirical fashion. The recitative explains that a tenor singer will arrive to perform a single aria. At one point, the contralto repeatedly sings "I have a nice phrase". The final act concludes with a mass suicide. Across the entire 65 minute score, only four notes are permitted to be performed, though in numerous intricate and rhythmical permutations derived from mathematical formula (Ericson, 1972).

Johnson's performance *Nine Bells* (1982) employs a set of nine bells suspended from the ceiling in a square three by three grid array. Each bell is positioned approximately six feet from its nearest neighbour, and the performer is expected to walk at a steady pace through the arrangement in diverse patterns responding to nine notated geometric forms. While moving around the grid, the performer strikes the bells that they pass according to a set of pre-determined logical sequences. The logic is applied to determine not merely the bell which is struck, but also the direction that the performer walks, the dynamics of the strike, the number of steps that take to perform a geometric form, etc. Arranged into nine sections (*bells*) each part begins and ends with a centre tonic bell which changes once per section. The visual element, with a performer walking decisively from bell to bell in sequence allows the audience to render the geometric pattern more readily than through merely the sonorous material (Nine Bells, 1982).

Tom Johnson's writings on compositional technique have had considerable impact on my methods employed in *Coil Cascade*. In his book *Self-Similar Melodies* (1996) he reveals his structuralist approach to music composition which supposes "that conscious awareness is more interesting than dreams, that it is better to know what one is doing that not to know and that objective reality is more interesting than subjective experience" (Johnson, 1996, p. 11). *Coil Cascade* takes Johnson's approach into account, first asserting that for every gesture there is an audible result, from micro rhythms unfolding from the texture of sliding springs, to the clipping of each spring onto the frame. For every sounding event perceived by the audience, it is possible to trace that event back to the gesture which spurned it. Also, one of Johnsons algorithms, *Transforming Ones and Zeros* (Johnson, 1996, 73) was modified and used to make real-time pitch choices across the whole composition, and it is explored further in Chapter 5.7.4.

Xenakis: Analogiques A et B

Analogique A (for string orchestra) and *Analogique B* (for sinusoidal sounds), composed between 1958 and 1959, signified a major conceptual and technical divergence for Xenakis in his compositional process. With this work, Xenakis moved away from concrete techniques, attempting to merge music composition, mathematic formula, and a conception of sound creation liberated from its inherent acoustic constraints (Di Scipio, 1998, p. 214). In this work, Xenakis attempts to “define the scheme of a mechanism as the ‘analogue’ of a stochastic process. It will serve for the production of sonic entities and for their transformations over time” (Xenakis, 1992, p. 81).

In *Analogique A*, Xenakis defines a mechanism which revolves around three variables: pitch, dynamics, and density. For each variable he utilizes *Transition Probability Matrices,* or TPM (effectively a form of Markov chain[2]) to determine the resulting value used at each moment in the scored composition. Instead of working with a twelve-tone system, Xenakis uses pure frequency, dividing the range of available pitches into six regions, which are separated into two groups (or sets). When passed through the Markovian-inspired TPM the mechanism will first choose one of two pitch sets, then propose a selected region from within that set, and lastly select a specific pitch from within the region. Parameters for dynamics, and density, are chosen in the same fashion (Di Scipio, 2006, p. 7-10).

According to Agostino Di Scipio, in its time *Analogique A et B* was considered a difficult and troubled composition. Some have argued that it is the least successful of Xenakis’ works, suggested by the fact that the whole piece is structured on conceptual mathematical and theoretical systems, which lead to an outcome weighed down by the aggregate of its formulaic

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[2] Described in detail in Chapter 5 of Curtis Road’s *The Computer Music Tutorial* (1996, p. 878-880).

processes, with a result deemed to be of negligible musical value (Di Scipio, 2006, p. 2). Nonetheless, in terms of relevance towards my own practice, I celebrate Xenakis' willingness to leave the whole development of a work to a structured process, and for giving that process the space and freedom to develop a compositional path of its own, regardless of its musical merit to the audiences of his era.

3.2. Historical context of material in music

In this section, I have attempted to select works which satisfy in some way the principles of the above noted works as well. That is, I have selected works which focus not strictly on the material, but which also consider elements of process and gesture, and as such in each work there exists a discernible link to my own presented works. In *Reunion*, I have taken considerable inspiration in my presented works in terms of Cage's use of physical objects and rules which guide a compositional process; in *Traversée du Labyrinthe Sonore* I find parallels to my own approach in *Spiel* for unique spatialization (mouth as resonator) and site specific installation (in-situ performance); in *Aquaphoneia*, which I worked on as a collaborator of Montanaro and Navab across eight months in 2016, the sound spatialization techniques explored bear similarity to *Spiel*, and the synthesis engine utilized in the *Drip* installation was an early prototype of the system employed in *Coil Cascade*.

Reunion (John Cage and Marcel Duchamp)

Reunion was first performed by John Cage with Marcel Duchamp on March 5 of 1968, at Ryerson Theatre in Toronto, Ontario. Later in the evening, it was performed as well by Duchamp's wife Alexina, and the composers David Behrman, Gordon Mumma, David Tudor, and Lowell Cross. Cross was the individual charged with designing and constructing the electronic chessboard, and he later described the Cage's compositional and technical approach in the Leonardo journal article *Reunion: John Cage, Marcel Duchamp, Electronic Music and Chess* (Cross, 1999, p. 35).

A noted motivation behinds Cage's indeterminant approach was his particular interest in separating his own identity (character, and personality) from his artwork. Cage was able to both achieve and rationalize this systematic approach by devising compositional operations from material existing outside of the musical domain. For instance, at times Cage would make use of the *I Ching*, or imperfections on written score paper to fulfill the needs his systematic indeterminate approach. In the case of *Reunion*, Cage turned to the theme of play and the object was a chessboard. Across a game of chess, a theatrical electronic musical performance unfolded (Cross, 1999, p. 41).

Cage defined for Cross two requirements for the chess board instrument: that it incorporated contact microphones which would create electronic noise on every movement and transmit oscilloscope imagery to televisions visible to the audience, and that "would result in the selection and distribution of sounds around an audience" (Cross, 1999, p. 37). Cross, a composer himself who had followed Cage's work for years, made a number of decisions on how the instrument would affect the outcome of the performance. Photoresistors were installed underneath each piece position. At the onset of performance: silence. With all pieces placed on each side, before game-play begins, the pre-game ranks of pieces were set to off when the remaining 32 photoresistors were exposed (as exists at the beginning of a game of chess). The chessboard featured 16 inputs which received sounds from the four collaborating composers, and eight outputs sent to a multi-channel speaker system. As pieces moved onto open board positions, incoming signals were triggered to playback. A sounding environment would slowly build up throughout performance, progressively immersing the audience in an expanding sound environment as more pieces moved into play at the beginning of game, and later a declining sound environment as pieces were progressively removed from the board, with all sounds removed from the composition as the last piece was removed from play (Cross, 1999, p. 37-38).

For Cage, and likely the audience, the actual manifestations of these performances were perhaps less than impressive. Indeed, for Cage, the self-taught intellectual and one of the most highly creative composers of the 20th century, the concept of *Reunion* was able to satisfy many of his objectives: indeterminacy, play, high theatre, and an aesthetic curiosity in everyday life. However, as a musical work the result was unsatisfactory. In one game, a player-musician lost quickly, never allowing the elemental system to entirely realize the full experience for the audience. Another game seemed to last indefinitely and was finally stopped mid-play as the player-musicians were wearied by the late hour, and the audience had by this point mostly left the theatre. Lastly, and most crucially, Cage had proposed that in an elegant game of chess, a refined musical process could unfold: that in the rules of chess, as followed through by the high performing chess player, an exciting compositional work could be revealed merely from movements of the players. However, across several games of chess, no truly elegant moves were performed by the players, and indeed no particularly interesting musical structure was revealed throughout (Cross, 1999, p. 41). After Cage performed the work once more the following month in Buffalo, the work did not appear again (Cross, 1999, p. 35).

Like Xenakis' in *Analogique A et B*, in trusting musical structure to pre-defined process, this work served as a fundamental inspiration in the creation of *Coil Cascade* and *Spiel*, as well as many of my earlier works. The piece also considers a material object, the chess-board, and active participants performing gestures within a defined space (the player-musicians, and the playing space). *Reunion* is one of the earliest examples I have been able to find across music history of a composer fully connecting material, gesture, and the algorithm, and though the actual performance of the work turned out to be less than satisfactory for Cage, his conceptual decisions in the development of this work have been highly influential to my practice.

Traversée du Labyrinthe Sonore (Éliane Radigue)

Originally created in 1970 for the French Pavilion of the Osaka World Expo in Japan, but too difficult to implement technically at that time, it was not until 1998 that Éliane Radigue would finally realise her *Traversée du Labyrinthe Sonore*, with the assistance of Laetitia Sonami. This work is a site-specific sound installation, which is notably adapted for every different location in which it appears, and consists of a sketched labyrinth map which is overlaid on top of a real cultural space, which the audience must explore to its eventual conclusion (and their exit from the labyrinth) (Vincente, 2015, p. 1).

At one well documented presentation, at the *Fondation Cartier pour l'Art Contemporain* in Paris, the audience progressed step by step through a labyrinth which was mapped through a Parisian garden filled with fauna and sculptures, across an open space café, past a water stream and pond, through an outdoor amphitheatre, and at the final stage into a spherical resonant concrete chamber, the heart of the installation. The audience is guided across the maze not merely by a paper map, but by sounds which appear to come from here or there, camouflaged by the exotic flowers and vegetation. The installation is guided by dynamic terrestrial processes: the solid earth, the flowing water, the heat from the fire, and the breath of the air; but also by the movements of the planets, and each ring in Radigue's map corresponds to a planet, with the heart of the labyrinth analogous to the sun (Vincente, 2015, p. 1-2).

What interests me particularly in this installation, is the attention paid to mixing the analog and digital domains, that what is perceived through crossing the labyrinth is not sound from a speaker but sound from a material (the plants, the pond, the sculptures) as transformed by space. Unlike Radigue's other works which are entirely fixed compositions, the recordings presented in this piece are changed for every exhibition. So, the audience perceives the piece differently each time it is presented, not solely because the context of presentation itself has changed, but also because the material used in the composition is malleable, and reformed for each event based on the spatial considerations and the materials available to the artist in the space. As well, Radigue does not work merely with sounds representational of the materials in the space (water flowing, birds chirping), but introduces digital or industrial sounds and intersperses these with the acoustic sounds, and processes them all together, to create a kind of hallucinatory sounding experience that mixes in digital sounds with live acoustic environments, leaving the audience incapable of determining which is which (Vincente, 2015, p. 2).

Aquaphoneia (Michael Montanaro and Navid Navab)

Aquaphoneia is an alchemical installation that transmutes voice into water. I worked extensively on this piece as a collaborator of Michael Montanaro and Navid Navab across the eight months prior to beginning my studies at the Faculté de Musique, as a researcher with the Topological Media Lab at Concordia University. The working methods explored across the creation of this work have been highly influential to my own practice, and I have integrated a number of the conceptual approaches and technical methods employed here back into both *Coil Cascade* and *Spiel*.

The installation is centered around a large Edison horn (or "witches' hat"), which sits in the middle of the room. This is the same type of horn was used in the early 20th century to create orchestral recordings on wax cylinders, with a needle on the end of the horn etching a representation of the acoustic vibrations directly into the wax. In this case, instead of using the horn to etch voice into *wax*, the instrument is used to etch voice into *water* as liquid sound. The audience is invited to speak into the horn, and as they lean into the horn to speak, they will notice an Edison cylinder recorder beginning to speed up, and water rushing out of the recorder from one of three glass pipettes. The liquid sound is sent by pipe to one of three installations: *Boil*, *Drip*, or *Whirl*.

In each of the three installations, the water flows out from above, and the audience perceives their voice flowing into the installation. In Boil, a large flask sits on top of a heating element which boils the liquid voices. When the flask pressure hits the correct threshold, a valve is released which sends boiling water through a tube where it is released as steam. The steam condenses inside of a copper cone, returns to water, and drips off the side of the installation. In *Drip*, water flows into flasks from above, and slowly drips onto three levels of plates. On the first level, each single drip is perceived as a word from the horn, as the water accumulates on the top plate and flows to the second, every drip is perceived as a phoneme, and as the water drips to the final level, it is transformed finally to phonetic vapour and silence. In *Whirl*, water flows into a flask, and slowly moves towards an ouroboros chamber where vowels are fermented, and consonants are distilled by a tornado that spins inside of a flask which sits on a pool of water. As the tornado hits the bottom of the flask, a cymatic representation of the voice is generated in the pool (Navab & Montanaro, 2016).

The particular working methods explored in this creation have been influential to both of the works I created across the duration of my studies. In *Aquaphoneia*, dozens of tiny speakers were hidden across the installation, shrouded by piping, at exactly the location where the material transformation was to occur. In many places, the amplitude of the acoustic sound of the material transformation (for example, boiling water), was matched precisely to the amplitude of the digital processes, resulting in a form of hallucination where the audience is entirely unsure what is acoustic and what is digital: the two are materially shaped into a cohesive hole. A similar approach was taken in *Spiel* (detailed in Chapter 6), with the sound actually emanating from the mouth, and with an amplitude ranging between a speaking voice and a medium yell. For the sound design of *Drip*, I used concatenative synthesis to automatically splice recorded voices from the horn into appropriately sized fragments (words and phonemes), which are then matched in real-time by timbre to the live sound of dripping water, ensuring that that digital voice which is perceived from the drip sounds as close as possible to the actual acoustic drip signal. This same approach was explored with a heavily modified system for the *Coil Cascade* performance, described in detail in Chapter 5.7.1.

3.3. The fusion of matter and algorithm in *Coil Cascade* and *Spiel*

My approach to the compositional works presented in this paper has been to integrate live sensors connected to the actual physical modulation of material objects, and to allow those sensors to feed software systems designed in Max/MSP and Pure Data to influence a variety of distinct compositional algorithms and processes in real-time. A significant element in my approach has been to first find material substrates which exhibit already sonically interesting qualities: this vastly simplifies the process of designing musical processes which are structurally interesting.

The first of the two works, *Coil Cascade*, employs an array of springs which are physically modulated by the movement of a performer. The spring is a particularly interesting material to work with in this manner, as it naturally produces repetitive movement which can be modulated by a performer (strong forceful gestures which impact randomness or noise into the arrangement of springs). As well, the spring has natural sonorous qualities which have been regarded highly for their sound processing capabilities for the better part of the last century. In *Coil Cascade*, I take the visually suggestive musical movement of the spring (as rhythmic gestures), and combine them with their inherent sonorous qualities. Piezoelectric sensors are used to track the spring's movement in real-time. Signals from the piezoelectric sensors are mapped to compositional algorithms which respond to the spring's movement. Many distinct systems are arranged together to determine the outcome of each performance, allowing distinct variability across each performance.

I have implemented an adaptation of Tom Johnson's "Transforming Ones and Zeros" (Johnson, 1996, p. 73) which takes a simple set of pre-determined numbers and continuously rebuilds them based on each gestural impulse which passes a certain acoustic threshold (determined by an envelope filter with multiple filtering capabilities). I have also implemented a type of recombinance (as described by Cope), utilizing the MuBu multi-buffer container (IRCAM Forumnet, 2018). This form of recombinance is concatenative synthesis, a synthesis technique which automatically reassembles pre-recorded compositional fragments based on a spectral analysis on an incoming signal. In this case, incoming signals are received from piezo-electric microphone attached to springs. Those signals are compared to a stored database of spectral information related to pre-recorded compositional fragments. Many compositional elements will appear in performance only when specific thresholds are reached, and there are elements which will appear in some performances but not in others, or elements which will appear at different points in performance entirely dependent on the velocity of the gesture.

In *Spiel*, the approach is similar. The mouth is employed similarly to its function in vocal performance, except the voice emitted from the lips is not that of the performer, but of the audience. The mouth is placed at the center of the performance. An accelerometer is placed beneath the chin which provides a real-time value for mouth movement velocity (see *Chapter 6.4.2)*. That value is used to influence compositional sound processing algorithms that include audio playback position selection, generative rhythms, and many varieties of gesture-mapped sound processes. The signal processing is performed in real-time by a miniature computer hidden on the performers body. Sound is then transmitted back into the mouth of the performer, and further processed by the physical formant shapes induced by the performer's lips and tongue. The mouth is effectively transformed into a material algorithm itself, connecting both the organic traits of mouth movement to the computational abilities of software running on the body-mounted computer. In performance, it can be difficult to discern where the organic functions begin and where the digital functions end.

4. Gesture in performance

4.1. On formulating gesture in digital art

In the electronic arts both screen and speaker-based performances widely populate the field, as explicated by Salter in *Entangled* (2010, Chapters 2 and 5), Adams et al. in *Transdisciplinary Digital Art* (2008, Chapters 2 and 3), and Lovejoy in *Digital Currents: Art in the Electronic Age* (2004, Chapter 4). However, in my recent compositional works I attempt to move beyond the speaker and the screen, towards a multi-modal performance practice which attempts to unify gesture, sound, and algorithmic process.

What is a gesture? The study of gesture is a broad field that is employed in many disciplines, and there is no commonly understood definition for what precisely constitutes gesture. The meaning of the term is largely discipline dependent, and in my compositional practice, I take a looser view than many of my contemporaries. Miranda and Wanderly in *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard* (2006) define gesture as "any human action used to generate sounds [...] refers to actions such as grasping, manipulation, and noncontact movements, as well as to general voluntary body movements" (Miranda & Wanderly, 2006, p. 5). In my practice, I certainly consider each of these actions as gesture, but I expand it to consider also the movements of non-human agents. In the presented performances two mappings of sound to gesture are considered: kinesthetic bodily gestures, and the movement of materials. In *Spiel*, I use an accelerometer positioned under the chin to provide real-time data of not only mouth movement, but also to provide an accumulative whole-body velocity reading (see Chapter 6.4.2). In *Coil Cascade*, kinesthetic gestures were created in tandem with the sound mappings (see Chapter 5.4), so the scraping gesture mappings consider both the gesture performed in scraping, as well as the original acoustic scraping sound.

On the question of gesture arises the question of the *natural,* or what can be perceived as such? In *Rhythmanalysis*, Lefebvre argues that there is no tendency in gestures towards *nature*. Gestures are shaped and understood according to the era or society in which they develop, varying widely in both their symbolic meaning and physical manifestation. Looking back at films from the early 20th century, one will notice a markedly different style of walking than is evident on North American streets today, appearing in films of that era as a brisk jaunt, though it may not have been captured very well by the limited technology of the day**.** In fact, natural movement itself bears no immediate relation to gesture, yet in the utilisation of gesture in a performance practice it is undoubtedly desirable for a gesture to appear *natural*. It is clear that gestures fluctuate not solely by historical era, but also by the cultural context, situational considerations, and a host of other variables (Lefebvre, 1992/2016, p. 47). Lefebvre states that "the representation of the **natural** falsifies situations. Something passes as *natural* precisely when it conforms perfectly and without apparent effort to accepted models, to the habits valorised by a tradition (sometimes recent, but in force)" (Lefebvre, 1992/2016, p. 47-8).

In both of my creations, Lefebvre's concept of *natural* gestural activity is used as both a primary performative element, and a guiding tool for the processes which unfold in performance. For example, in *Coil Cascade* I study gestural activity at the level of visible metric gestures which can be mapped to sound, such as a spring repeatedly moving up and down mapped to a steady bass sound, or the slapping of a spring into another resulting in aggressive sound decaying slowly relative to the strike velocity, before resolving to subtle acoustic spring sizzling. Across my creative process, I pondered the spring in its historical acoustic context, as a reverb processor, and thus of the expectation the audience was likely to have of such an instrument. I considered the actual acoustic output of the instrument, and the varying timbres I was able to produce by physically interacting with the springs. Lastly, I considered the actual gestures that were apparent to the audience: bodily gestures, and spring gestures. Then I looked to map that movement in a way which seemed to me, subjectively of course, *natural* to the bodily and spring movements, and to the acoustic quality of the instrument. All of these creative choices were unremittingly counterbalanced by my own personal aesthetic tastes as they relate to contemporary experimental electronic music. This connects to Lefebvre, in that the *natural* itself is always evolving with the tastes of the era. To instill human qualities in my work, I have looked to respond to historical and contemporary material themes relevant to the milieu in which I function.

4.2. Temporal modeling vs. state transitions.

I have drawn a distinction between state transitions, a technique commonly employed in electronic performance (through the flipping of switches, and pushing of buttons), and temporal modelling (the continuous transformation of material in correlation to movement). I have deeply explored temporal modelling across the creation of the composition and interactive design in *Spiel* and *Coil Cascade*.

I attempt to avoid fixed transitions in electronic performance. Instead of using button presses or triggers (without gestural process) to move dramatically between parts and paths in performance, I have integrated sensors in my performance systems which are capable of reading, analyzing, and translating signals in real-time. This enabled me to design sounding systems and algorithmic structures which elicit a natural response to gestural activity. Illustrating my dedication to the principle of correlating sound to continuous movement, in *Coil Cascade* I explore material micro rhythms through real-time concatenative synthesis (also known as audio-mosaicing). This is a technique that analyzes millisecond segments of incoming live acoustic textures (like sliding springs). These incoming signals are compared to databases of similarly analyzed and segmented digital sounds. New digital forms of sound emerge from the instrument, with alike digital segments replacing the acoustic segments in real-time. (Navab, van Nort, and Wei, 2014).

It is only in the last 15-20 years that it has been practical for artists to work with real-time digital signal processes in this way. The capability to engage with these systems has been enormously affected by the development and proliferation of sound processing languages (Max/MSP, Puredata, and Supercollider). This is augmented by the rise of powerful and portable computer systems capable of running digital sound applications in timing sensitive applications, and the wide-spread availability of easily programmable microcontrollers (like the Arduino) for fast data acquisition (Miranda and Wanderly, 2006, XIX). In fact, the production *Spiel* would have been entirely impossible prior to the release of the first embeddable Raspberry Pi computer (Raspberry Pi Foundation, 2012), which is hidden inside of the performers costume and used for all of audio processing and body movement data acquisition.

4.3. Gesture Mapping

Extensive technical and aesthetic experiments in gesture mapping have been pursued during the creation of *Coil Cascade* and *Spiel*. I will provide a theoretical overview utilizing the two references which have been most beneficial to my work: Michel Chion’s modes of listening, and a paper by Baptiste Caramiaux entitled *Mapping Through Listening* (Caramiaux et al., 2014). In the last part of this section, I will describe the specific mapping strategies employed in my performances.

4.3.1. Chions' modes of listening.

Michel Chion defines in his seminal text *Audio-Vision: Sound on Screen* (1994) *casual listening*, *semantic listening*, and *reduced listening* (Chion, 1994, 25). At different points across the performances of *Coil Cascade* and *Spiel*, all of these listening modes are explored.

Chion defines *casual listening* as the most common type of listening, which involves listening to a sound in order to acquire information on its origin or cause. It is employed when tapping a plastic container to determine its contents. In this mode, sound provides information that is not available through other means (visual, touch). Chion defines this as a somewhat deceptive form of listening, as the ability to precisely determine how much of a material resides inside of a container is not exactly determined by listening (Chion, 1994, 25-6).

He defines *semantic listening* as that which employs a code or language to decipher the meaning of a sound. Spoken language and Morse code or two forms of this mode. This is a very complex form of listening, which is also the most extensively studied and pertains particularly to the fields of linguistic studies. While significant, the mode of semantic listening often discards valuable information, such as pronunciation, which may not be absolutely pertinent to the comprehension of language (due to regional variation), but is unambiguously significant in the field of sound (Chion, 1994, 28).

The last mode of listening is *reduced listening*. Inspired by Pierre Schaeffer's work, Chion defines reduced listening as the mode which studies the quality of the sound itself, that which strips the sound of its cause and meaning and instead focusses on its acoustic merits and sonorous qualities. Through reduced listening, the descriptive information of a sound cannot be determined through a first listening. It is necessary to repetitively listen to a sound before extracting this information. To repetitively listen to a sound is possible only through first creating a fixed recording of the material, as it is otherwise impossible to produce exactly the same sound twice (Chion, 1994, 29-30).

In the compositional method and gestural organization of the two works presented herein, the approach to mapping is relevant to two different modes of listening proposed (*casual* and *reduced)*. In the case of *Coil Cascade*, a *casual listening* mode is suggested at the beginning of the performance, with a perfect 1:1 mapping from the acoustic input gesture to the acoustic output. The naked acoustic spring sound is acquired via piezo-electric carabiner microphones (piezo-electric microphones attached to welded plates on steel carabiners, detailed in *Chapter 5.5.1*) and routed directly into the speakers. Throughout the first two minutes of performance, I perform entirely acoustic gestures through simple scraping and plucking gestures. In *Spiel*, recorded voices are at first presented to the audience with a 1:1 *casual listening* mapping. Thus, the outputted sound from the performers mouth is exactly as it was spoken into the instrument by the audience, without any added sound transformations. Then, the performer moves into an improvisatory phase related to the mode of *reduced listening*. Here, the performer begins to improvise upon the raw recorded material : employing kinaesthetic gestures which continuously control sound transformation algorithms in real-time. A chin-embedded accelerometer allows for precise correlation of sound to mouth movement. Likewise, the lips and tongue are able to modulate the sound material purely in the analog domain, by physically impacting formant shapes upon the outputted instrument sound.

Mapping through listening

In the composition of the two works, the paper *Mapping Through Listening* (Caramiaux et al., 2014) was a significant inspiration in the approach to gesture-sound mappings. Caramiaux stipulates that human perception of object, space, and environment is shaped by the functions of the body and its physical ability to interact with the world. Listening, as one faculty of perception, it is fundamentally linked to the process of both acquiring and applying knowledge in concert with environmental interaction. The authors note also that in digital musical instruments (DMI's) there does not necessarily exist an inherent connection between gesture energy and acoustic energy, the mapping is created digitally: relationships between inputs and outputs of real-time data can be defined arbitrarily (p. 34-35).

The authors describe a number of interaction scenarios, of which two will be detailed here. The first scenario is called "shaking", where a performer's shaking movements were used to create percussive sounds. Linked to *causal listening* the performer physically demonstrated a shaking gesture, and a mapping was implemented as a 1:1 correlation between gesture energy and energy of the sound performed. This mapping required a learning phase, where an offline analysis was performed on a database of recorded sounds (Caramiaux et al., 2014, p. 39). In the learning phase, individual sounds were automatically segmented using an onset (amplitude based) analysis method, where each segment was described by its amplitude, and stored in a database. In the playing phase, the performed gestural data was analyzed in real time by computing its relative energy, from which a segment was automatically selected from the pre-processed database of sounds. The intensity of a performer's shaking gesture was directly correlated to the intensity of the resulting synthesized segmented sounds. The authors utilized wireless accelerometers to sense gestural movement, and also implemented a k-nearest neighbour (k-NN) search algorithm allowing a number of neighbouring (and thus highly related) segments in the database to play back at any given time and provide variation in the synthesized output (p. 39-40).

The second scenario proposed in the paper is referred to as "shaping". In this scenario, a performer controlled the morphology of a sound by "tracing" in the air the particular sound features they wanted to control. In this way, the scenario is related to *reduced listening* rather than *causal listening*, as the performer focussed their attention on the acoustic and temporal features of the sound they intended to produce (as opposed to the implied acoustic/temporal features of the gesture itself). In the case of "shaping", a learning phase was again utilized in order to create a detailed analysis of a database of sounds. The playing phase began with a gesture, where the performer drew the general morphology of a sound they wanted to play, while the sound played back in real-time with the added time domain reinterpretations (prescribed mappings) translated from the input gesture. A sound was chosen for the first gestural impulse, using a real-time morphology matching algorithm which determined at each moment in time the sound descriptor in the database matched most closely the input gesture morphology. The algorithm then aligned the morphology the selected sound to the gestural impulse, allowing for smooth real-time transitions between recognized gestures (Caramiaux et al., 2014, p. 40).

In *Coil Cascade*, the gesture-sound mapping was highly influenced by the ideas presented by Caramiaux and his colleagues. Using the "shaking" scenario, I implemented a nearly identical system, through a form of concatenative synthesis built upon IRCAM's MuBu platform (see Chapter 5.7.1). Whole pre-recorded compositional fragments are passed through an amplitude analysis stage, where all of the significant amplitude on-set positions have been pre-written into a database in advance (the learning phase). Then, during performance (the playing phase), the live microphone signals are analyzed for amplitude on-sets in real-time and compared to the pre-built database of sounds. Small fragments of sound are pulled from the database and concatenated together in real-time, and further processed by envelope followers, to create sounds which are always continuously responsive to the topological figure of the spring. At times, the sounds generated are related to the acoustic gestures imbued on the springs, and at other times they are totally alien to the acoustic material of the spring by way of extensive employment of k-NN nearest neighbour segment selection, and various filtering techniques. Envelope followers are used throughout to control the amplitude of the synthesis system, to ensure the envelope of the digital sounds remains precisely mapped to the acoustic gesture of the spring.

In reference to Caramiaux's "shaping", my earliest experiments with the spring began by stretching the spring with an assistant holding one end, and holding the other end in my hand with a piezo-electric microphone pressed against the spring. My assistant and I performed as many gestures as we could imagine on the spring including hitting, scraping, swinging, tapping, and rubbing. These experiments played a significant role in the mapping decisions that were employed, as well as on some of the physical gestures that I would later use in performance. Across the first two movements of performance, I created gesture to sound mappings which clearly respect the actual acoustic and gestural qualities of the spring. I attempted to find a way for the acoustic sound of the spring and the digital forms mapped onto them to fuse into a single cohesive whole. I copied one of Caramiaux's approaches, in allowing the initial gestural impulse to trigger a transient sound. Following the triggered transient, a second sound arises from beneath the gestural impulse. This technique was often performed using a triggered sample on the first gestural impulse, followed by an acoustic spring sound appearing from beneath the transient by way of a side-chain compression process.

5. Coil Cascade

5.1. Concept

Coil Cascade is a live sound performance that seeks to exploit the performative potential of the common coiled spring. A seven-foot-tall rectangular structure stands on stage, shrouded in light. In performance, an array of 18 springs are individually hung, stretched, scraped, plucked, bowed, and otherwise set into motion. Throughout the 20-minute performance, I transform the spring into an expressive and continuously responsive material performance instrument.

The coiled spring was chosen as the concrete material for this performance for three primary reasons: its inherent topological material qualities (see *Figure 1*), the sounding characteristics, and the springs' history in sound processing and recorded music. The common coiled spring was first produced in the 15th century and began to be mass produced in the 18th century at the dawn of the industrial revolution. The spring is a fundamentally an energy storage device, manufactured for and implemented into millions of diverse products, from automotive machinery, to circuit breakers, hinges, furniture, watches and speakers (Diamond Wire Spring Company, 2018). Designed to remain resilient across many strenuous deformations of the original topological figure, the spring can be manufactured from a variety distinct types of material including stainless steel, carbon alloy, copper, bronze and plastic. In choosing springs for precision mechanical tasks, engineers look to various material factors including tensile strength, elasticity, hardness, corrosion resistance, temperature resistance, magnetic permeability, and electrical conductivity (Acxess Spring, 2018a).

One of the key texts I have referred to across the creation of the performance is Henri Lefebvre's *Rhythmanalysis* (Lefebvre, 1992/2016). In *Rhythmanalysis,* Lefebvre argues that our mode of perception functions to contain and conceal repetitive forms: "Our sensations and perceptions, in full and continuous appearances, contain repetitive figures, concealing them. Thus, sounds, lights, colours, and *objects*. We *contain* ourselves by concealing the diversity of our rhythms: to ourselves, body and flesh, *we* are **almost objects**" (Lefebvre, 1992/2016, p. 20). Through a process of unification between gesture, sound, and algorithmic process, I attempt to reveal the concealed natural repetitions which exist at many scales in our surrounding environment. In reference to Lefebvre: textural sounds (micro-rhythms) of springs sliding are slowed down and revealed to be rhythmic, while visually apparent metric movements are mapped to sound and revealed as sounding metric rhythms. In this performance, I build morphing electronic forms that contort in time with the natural topology of the spring. Sound is shaped in real-time as it modulates to spring motion.

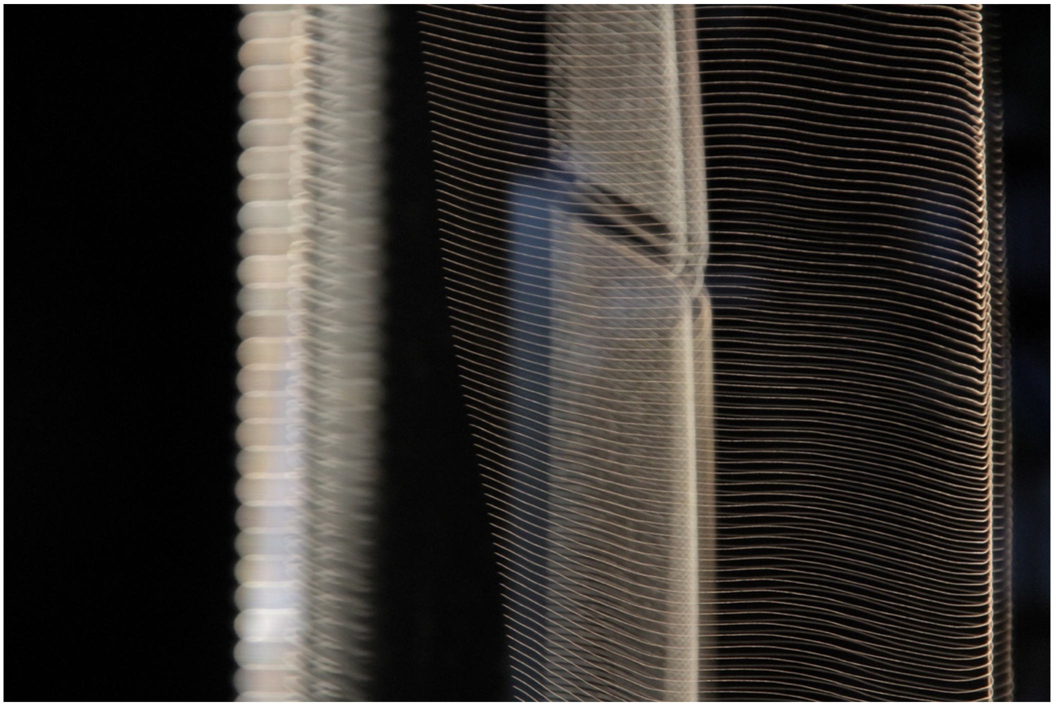

Figure 1: An example of the deformation of the springs' topological figure in Coil Cascade performance.

5.2. Object

In this work, my interaction with the spring forms only part of the performance. Otherwise it serves to gesturally set up or unfold a process as I engage with the object. I give precedence to dynamic processes over static objects in order to examine the relationships between human and non-human agency in performance. Oversized steel extensions springs are re-strung across the structure in performance, moving between the many embedded carabiner anchors. At moments springs swing alone in space, activated by their own resonant harmonic frequency and embedded electromagnetic coils.

After many acoustic experiments with springs forged from several different materials, I determined that springs made from the high carbon steel alloy 'music wire' exhibited the most detailed and nuanced sonic behaviour as compared to stainless steel and plastic-coated springs.

Very early in my process, I realised that I would need to source the widest and longest springs I could acquire and physically deform, as most springs on the market are too small or thin to be very visible to an audience even from a distance of a few meters.

I investigated compression springs, extension springs, torsion springs, and tapered springs, and finally made a selection of 18 extension springs which were used across the entire performance instrument. Each extension spring is 36” long unstretched with a diameter ranging from .25” to .875”. Springs were carefully chosen for the amount of initial tension, wire diameter, and spring rate (the amount of weight required to deflect a spring one inch [Acxess Spring, 2018b]). I acquired my springs from the Century Spring Corporation, California, and carefully analyzed their product datasheets to find springs that could be physically deformed in performance through stretching, pulling, shaking, and striking. At the end of the second movement, springs are struck by hand and rhythms are generated based on the frequency at which the struck spring responds vertically. In the third movement, all of the rhythms and pitches are derived from the natural harmonic frequency of the spring, or divisions thereof, which are activated in space by a set of tuned electromagnets. For this movement, I selected six identical model E-39 springs chosen for their malleability and a low initial tension of 9.4lb/in (Century Spring Corp, 2018).

5.3. Form

5.3.1. Compositional structure

The performance has been structured as three separate movements each derived from a known physical quality of the industrial spring: *tension* (i), *elasticity* (ii), and *conductivity* (iii). In each movement, music is generated through real-time processes which precisely model the topological figure of the spring in space. Inspired by the first electronic sound processor, Hammond’s “reverberation apparatus” (Hammond, 1940), the spring serves not merely as controller or interface, but rather as compositional participant: a computational substrate capable of fundamentally imparting its material characteristics (acquired by piezo-electric microphones) onto the sound material. Likewise, through the appropriation of compositional algorithms sourced from *Self-Similar Melodies* (Johnson, 1996), the spring signals acquired by piezo-electric microphones are mapped to algorithm parameters and used to determine the outcome of pitched musical passages.

The compositional structure was largely determined by the constraints of the physical apparatus and its acoustic character. I sought to define gestures that were indicative of the material quality explored in each of the three movements. In each movement, the continuous transformations of the spring's topological figure was mapped to digital sound processes. While there are many variable elements introduced into *Coil Cascade* through the variable response of the instrument, each gesture was organized into a linear score which was comprised of 38 individual score blocks. Each score block visually defines one or more individual gestures as well as the order in which they are performed. Individual score blocks are paired with an associated global instrument preset. Presets are stepped through progressively through the end of the performance, via one of four foot pedals positioned throughout the performance structure.

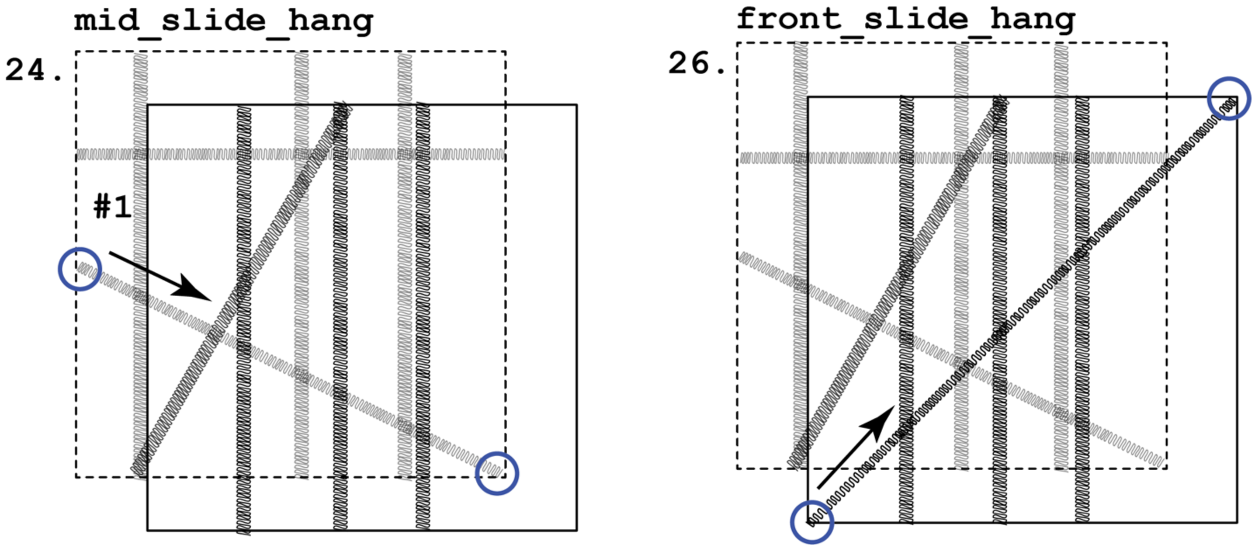

Figure 2: Two example score 'blocks' from Coil Cascade.

The score (see *Figure 2* and *Appendix III)* outlines every major gestural element, and roughly defines the dynamic response of each gesture, but within this broad outline there exists considerable variability in both the way the gesture physically plays out in space, and the way the physical apparatus and the digital instrument (see *Chapter 5.6*) will respond to the thrust of this gesture. In performance, I am free to soften the attack to my tapping, increase the velocity of my plucking, and hasten the rate of my scraping. I am free to perform each gestural score block longer or shorter as the performance unfolds.

The digital instrument fundamentally relies on algorithmic systems which continuously modulate sound material based on the visible deformations of the spring's topological figure. So, the digital instrument is itself able to introduce variation into the work. For example, depending on the *force* of a gesture, sound events will appear more subtle, or may not occur at all. A series of equalizers, gates and trigger detection algorithms are stacked after each microphone preamp, the settings of which have been customised for each score block. With careful signal cooking, it is possible to allow certain events to sound based on the specific spectral qualities of the acquired acoustic signals. This technique is employed extensively in the performance, to ensure that the sounding quality of the digital instrument is constantly changing relative to the acoustic energy performed. Likewise, it works to ensure that each performance is meaningfully different to another.

5.3.2. Sound material

In *Coil Cascade*, I bind real-time compositional algorithms to the movement of matter. My digital performance instrument analyzes the acoustic sound of the springs, captured from six contact microphones attached to the springs, and translates those signals into real-time electroacoustic music derived from the motion of springs. The performance moves back and forth between acoustic material textures and morphing digital sounds, fluidly shifting between the two sonic spaces dependent on both the position of the score, and the variable energy of every interaction and gesture.

As well as the physical material itself, the natural acoustic qualities of the instrument inspired a performance drawn from my experience in electroacoustic, acousmatic, and industrial music. Structured into three movements, the material and digital sound matter for each section is derived form a material quality of the spring. In *tension* (i), the spring is drawn taught and scraped, at first appearing entirely acoustic, then building up into granularized distortions of recorded scraping sounds. The granularization is continuously modulated by the sometimes subtle and elsewhere forceful scraping performed on the spring. Finally, the springs are plucked and struck. Sound to action mappings drift and modulate to the gesture, perceptibly modifying the response at each moment. In *elasticity* (ii), springs are pulled and snapped back into each other. On each impact they generate pitched tones which are modulated further by the material envelope; as the digital pitched sounds fade out, the subtle acoustic "hissing" of springs lightly rubbing into each other is amplified and brought into focus. In *conductivity* (iii), springs move in space activated by their own natural harmonicity. Electromagnets are placed next to the springs during performance and pulsed at specific frequencies to mechanically induce rhythmic material sounds. This effect is also perceived visually, as the spring movement is cut by stroboscopic light that produces "snaking" spring images. The movement is timed to an electronic score composed of hard hitting mechanical rhythms and "squelching" synthesizers.

Most of the digital sound material in this performance was composed from recorded fragments of digital modular synthesis patches, and multi-sampled complex and pitched sounds. In one part of the system, fragments were repurposed as corpus sample banks for IRCAM's MuBu multi-buffer objects (IRCAM Forumnet, 2018) in Max/MSP, which is described further in *Chapter 5.7.1*. Acoustic signals from the springs are routed to play back spectrally similar grains pulled from the corpus bank. Pre-composed sound fragments are re-organized into sonically diverse and variable content, continuously correlating to the acoustic motion of the material. In another part of the system, a sample player has been embedded. The sample player allows loading of multi-sampled instruments which receive MIDI note messages across a nine tone equal temperament scale (9ET) for triggering sounds whenever a pre-defined amount of energy has been put into the instrument. These triggered sounds are then re-processed by a parallel set of envelope followers which map the amplitude of the acoustic spring to control the amplitude of the digital timbres.

In the process of creation, it became clear that at certain moments in the performance I would need to re-arrange the springs. In particular, I had three ~90 second sections of spring rearrangement, where no discernible acoustic energy was put into the piezo-electric microphones. I composed interactive "spring-clipping" sections as part of the performance. A single pushbutton is attached to each carabiner (see *Chapter 5.5.2*). This button is pressed whenever a spring is unclipped from the frame, to trigger sounds. These sounds are composed of actual recordings of the clipping and unclipping of springs. As well, a pushbutton press triggers the playback of part of a fixed electroacoustic drone composition, with each pushbutton press moving closer towards the end of the composition. The recordings of clipping and unclipping springs were heavily processed using the *Composers Desktop Project* (Composers Desktop Project, 2018) and Trevor Wishart's *Soundloom* (Trevor Wishart, 2018), which was employed in part to reference acousmatic computer music from the late 1980's and 1990's. The particular *CDP* processes used include amplitude domain processes like granular, distortion, pitch shifting, and spectral processes like formant filters, spectral blurring, and spectral morphing. The background drone music consists of two oscillators with extensive modulation, a digital model of a tape delay, and two comb filters.

5.3.3. From performative elements to graphic scoring

The most important performative elements in *Coil Cascade* are laid out on the six-page score which is divided into 31 individual gestural score blocks. It consists of arrangements of 10 primary gestures which are introduced in various configurations across the performance. The entire score is attached in *Appendix III*.

Figure 3: Hang spring symbol.

1. Hang

   A spring is picked up from the ground and attached to a carabiner or removed from one carabiner and attached to another carabiner.

Figure 4: Remove spring symbol.

2. Remove

   A spring is removed from a carabiner and placed on the ground or removed from one carabiner and attached to another.

Figure 5: Downward spring scrape symbol.

3. Downward scrape

   Using a steel guitar thumb plectrum, I scrape downwards on the spring. I accentuate the scraping of each individual rung of the spring, creating natural material rhythms which are processed by the digital instrument.

Figure 6: Upward spring scrape symbol.

4. Upward scrape.

   With a guitar plectrum, I scrape upwards from the base of the coil, accentuating each individual rung.

Figure 7: Pluck spring symbol.

5. Pluck

With the plectrum in the right hand, I pluck downwards on a spring, flicking hand upwards. This creates a repeating sustained sound, as the spring moves up and down in response to the force of the pluck.

Figure 8: Pluck and mute spring symbol.

6. Pluck and mute. I reach towards a spring in motion, steady it with both hands, silencing it.

Figure 9: Spring hand-hit symbol.

7. Hand hit

   I hold the top of the spring with my left hand and hit the spring with palm of my right hand, with the decay of the sound dependant on the strength of my left-hand grip.

Figure 10: Pull down on spring symbol.

8. Pull down

   I pull down vertically on the spring, generating a repetitive up and down movement on the coil, with a ‘tick-tick-tick’ rhythm dependant on the natural resonating frequency of the spring.

Figure 11: Slide spring symbol.

9. Slide

   I attach a spring over top of another spring and slide it back and forth, creating a rough grinding texture.

Figure 12: Pull back spring symbol.

10. Pull back

    I pull back on a spring and release it, generating a forceful impulse into the arrangement of springs.

5.3.4. Visual inspirations

The visual design of *Coil Cascade* is inspired in part by two Italian futurist sculptures: *Scultpture en bois, carton et fils* (1914) by Giacomo Balla (image omitted due to copyright and inability to acquire permission for publication, printed in *Le Futurism* [p. 17], by M. Calvesi, 1976, Paris: Tête de Feuilles), and *Danse de Saint-Guy* (1919), by Francis Picabia (see *Figure 13.)*

In Pacabia's piece, wires are arranged inside of a wooden frame. The individual wires cut across the frame both vertically, horizontally, and diagonally. At one point, the wires meet in the middle of the frame, while at another, the vertical wires cut over top of the diagonal wire beneath, creating three four distinct new quadrants inside of the frame.

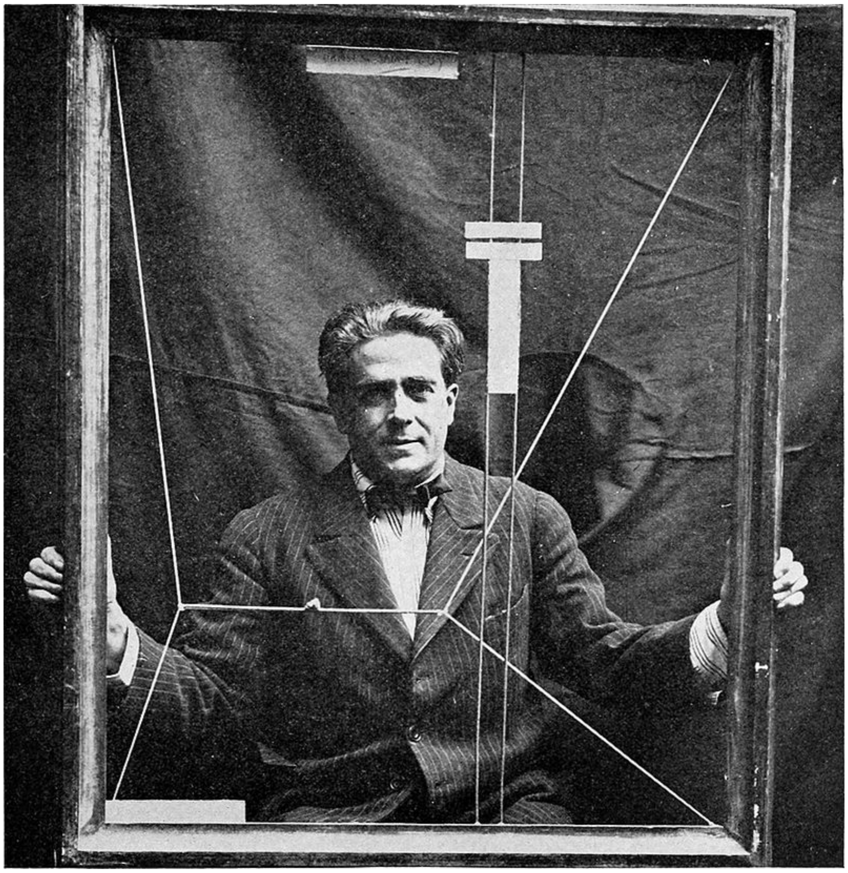

Figure 13: Francis Picabia, Danse de Saint-Guy (1919),
(Photograph ©1922,Picabia, now in public domain)

My structure was designed to have a minimal appearance, so that it could essentially be veiled from view of the audience, leaving the impression of springs floating in space. The performance structure is seven feet tall, five feet wide, and four feet deep, painted black, and with many carabiner hooks visible throughout the frame. Electronics and cables have been mostly hidden, wrapped inside of the frame, and from a twenty-foot audience distance it would appear that the only material used in performance is the spring. Six spooled electromagnets are positioned around the frame and are raised from the frame for the final movement. Steel springs are hung in various arrangements, variously running vertically, horizontally, and diagonally, sometimes tying from bottom to one side of the structure, at other times attached diagonally across from the front right to back left corner.

Light is used minimally in this first iteration of *Coil Cascade*. The front and back of the structure are treated as two separate panels, each lighted on the left and right of the front of the panel, and also from the back at an angle. At the start of the performance, first only the back panel is lit, and as springs start to be hooked across the structure, light on the front panel will fade in. Across the performance, structural lighting follows this same formula: if I am engaging with a spring on the front panel with no further springs hooked to the back panel, the back panel will remain dark until I return to hang a spring.

5.4. Structure construction and prototyping

The physical performance structure went through three design iterations.

5.4.1. First prototype

The first structure (*Figure 14)* was eight feet long, and six and a half feet tall, and constructed from wood. It was designed as a simple experimental prototype structure, to quickly hang springs and experiment extracting and processing their acoustic qualities. It was decided finally that the structure was too long, heavy, and somewhat physically unstable in performance.

Figure 14: First prototype spring structure.

5.4.2. Second prototype

The second structure (note *Figure 15*) was built from steel pipe. The pipes were threaded and universal joiners were used to construct the frame so that it would be possible to disassemble. This iteration was five feet wide, and six and a half feet tall, which proved to be slightly too short but otherwise an appropriate format for a single paneled (two dimensional) instrument. The structure still felt somewhat unstable, and while the steel pipe looked good aesthetically in contrast to the steel springs, it bared an unfortunate resemblance to a coat rack.

Figure 15: Coil Cascade second prototype structure. At the base of the structure, the steel pipe and pipe fittings used in construction are visible.

5.4.3. Final instrument

Finally, I determined that a three-dimensional structure would be more useful in performance, as it would enable me to hook springs diagonally across a space without requiring theatre weights. I designed a rectangular prism seven feet tall, five feet wide, and four feet deep, manufactured from standardised black aluminum extrusions (see *Figure 16*), which could be disassembled easily and are not particularly heavy. Using standardised steel hardware, it was possible to use very rigid eye bolts and connectors which are screwed directly into the frame, ensuring that the carabiners are always held firmly in place, and that the electromagnets can quickly be raised and locked in position for the final movement. Given that everything is connected by strong steel bolts, the structure itself can become a resonator, and two piezoelectric microphones have been positioned strategically on the structure to capture that resonance and use it as a kind of plate reverb to further process acoustic spring signals.

Figure 16 Final instrument, complete structure in performance.

5.5. Electronics design

I experimented with a wide range of sensors to capture the gestural activity of the springs, including tension sensors, accelerometers, and sonar sensors. However, I finally settled on using only three different electronic sensors.

After the first performance at the Faculté de musique[3], a new system for handling the various sensors and switches was designed. The carabiners, foot switches, electromagnet coil actuators and lights are all plugged into a single "master spring control box" (see *Figure 17.*) Except for the carabiner microphones, which are monitored by the computer with an eight-channel sound card, this box handles all of the sensor input and actuator output. A single Teensy 3.1 (PJRC, 2018) handles all of the input and output, which includes six channels of foot switches (¼ inch input), twelve channels of carabiner switches (¼ inch input), six channels of electromagnet control (¼ inch output), and six channels of light control (five pin DIN output). BUZ FET11 transistors controlled by a Max/MSP patch are used to gate two 36V power supplies which drive both the electromagnets, and 100W LED lights.

Figure 17: Master spring control box, including inputs for foot pedals and carabiner buttons, and outputs for electromagnets and 100W LED lamps.

5.5.1. Carabiner microphones

I have six carabiner-microphones bolted to my structure in various positions, and two contact microphones embedded directly into the structure to capture 'spring clipping' sounds and also occasionally to use as a plate reverb to process acoustic spring signals.

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[3] This performance was held in April, 2018, at the Faculté de musique at l'Université de Montréal, in the *Multipistes* studio.

The primary sensor used in performance is a set of eight DIY piezo-electric ‘contact’ microphones (see *Figure 18*.) I designed my microphones with two piezo-electric ceramic/brass plates, which are positioned out of phase with a layer of silicone sandwiched in between. This creates a balanced signal, and most of the inherent ‘contact’ microphone noise is electrically subtracted. I welded small steel plates to steel carabiners, clamped the microphones to the plates, and applied a generous amount of epoxy to permanently mount the microphones to the carabiner.

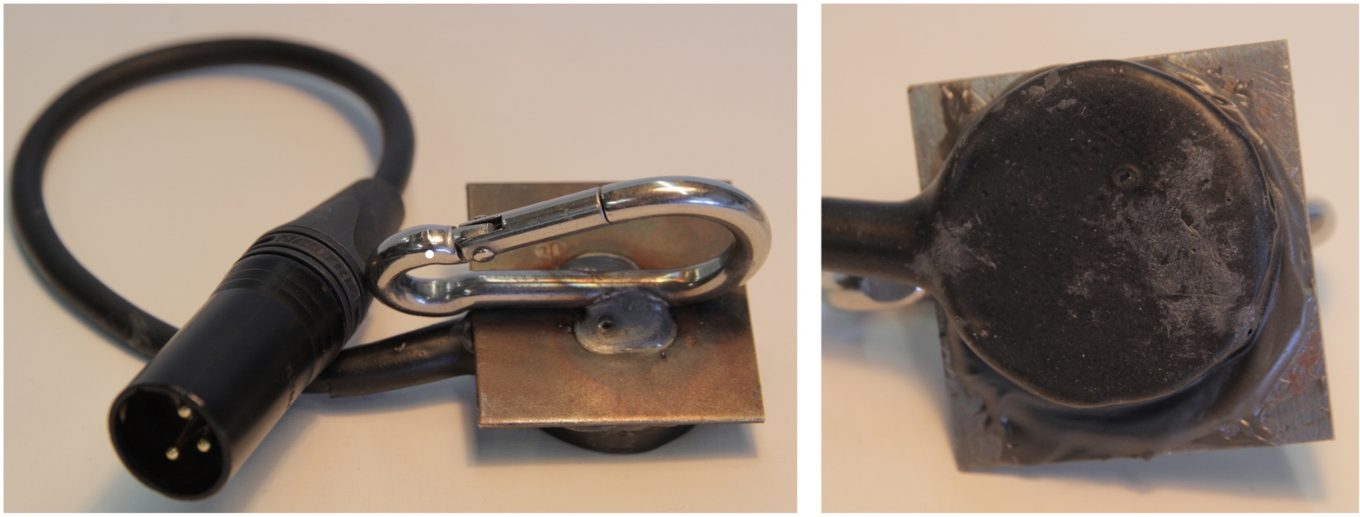


Figure 18: Carabiner piezo-electric microphone.

5.5.2. Carabiner buttons

Since the first presentation of *Coil Cascade*, I have added individual buttons to the back of every non-microphone carabiner. The buttons are epoxied to a thin piece of wood, which itself is epoxied to a metal plate and welded to the side of a steel carabiner. Using these buttons, during the “spring hanging” sections, I can trigger processed spring clipping sounds in synchronization with hanging gestures, and also modulate an acousmatic-drone composition which serves to transition between each movement.

5.5.3. Foot pedals

The final sensor employed in *Coil Cascade* is a set of four momentary foot pedals. These are standard foot pedals used for electric pianos to control a sustain parameter and have a 1/4" male output, which connects to the "master spring control box", described above. They are placed in different positions around the structure, allowing me to subtly trigger new score block presets.

5.5.4. Electromagnetic coils

I built a set of six electromagnet coils and embedded them with adjustable bolts that clamp into the aluminum structure (see *Figure 19)*. I created a 3D model of a spool, which was physically realized with a 3D printer. I then mounted the spools onto a steel rod that was attached to a drill press. Using the drill press at its slowest setting, I wound 28AWG enameled copper wire onto the spool. A small mount was laser-cut for each spool and attached to the frame with brass wingnuts. A ¼" male jack extends out of the coil and into the "master spring control box", which pulses 36V into the coil at a variable rate defined by a patch written in Max/MSP.

By taking very careful measurements of my stretched springs, I was able to find a position on the spring where I could activate up to four different resonant harmonic frequencies of the spring (1/6th of the length of the spring), creating physical visual representations on the material. I then pulsed the electromagnet coil with a short burst of voltage at the stop-watch determined frequency, and carefully adjusted the frequency until the desired effect was visually apparent. Every spring had slightly different harmonic frequencies due to the manufacturing process, and I had to determine each of the four fundamental frequencies for all six springs.

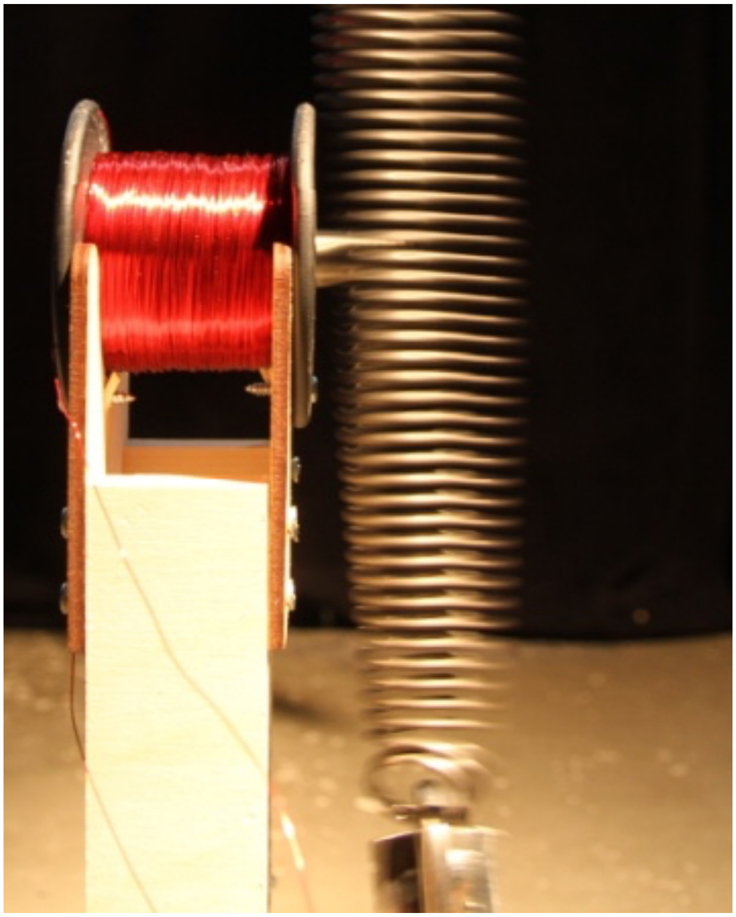


Figure 19: Self designed electromagnetic coil.

5.6. The digital instrument

5.6.1. Audio mosaicing

I chose to use concatenative synthesis, in the form known as audio-mosaicing, as the primary synthesis engine for this performance.

Concatenative synthesis functions by leveraging a database of sound fragments (the 'corpus') to assemble new sounds according to a target input. In Coil Cascade, the corpus is a database of sounds built from pre-recorded synthesized sounds and compositional fragments. Each sound has been segmented by an analysis stage and extracted numerical features (or audio descriptors) are automatically attached to each database element (Navab et. al., 2014, p. 2-3). To implement concatenative synthesis in Coil Cascade, I have employed MuBu for Max, a free set of objects for Max/MSP by IRCAM (see *Figure 20)*. At its core MuBu is a multi-buffer container for audio, audio descriptor, and motion data (IRCAM Forumnet, 2018). It allows for individual segments of multiple audio buffers to be triggered and re-assembled together in real-time.

MuBu has been implemented in the performance system as follows: short 20-30 seconds musical phrases are prepared in advance and loaded into a MuBu buffer where they are analyzed by an OnSet amplitude analysis, which determines which audio samples pass above a certain threshold for a defined amount of time. Live incoming signals from my piezo-electric microphones are analyzed in real-time with an OnSet analysis, and routed to control corpus segment selection. With tasteful synthesis patching, and careful consideration of gestural representation, I am able to output new audio signals composed of short musical phrases which directly correlate to the slightest gestural spring activity.

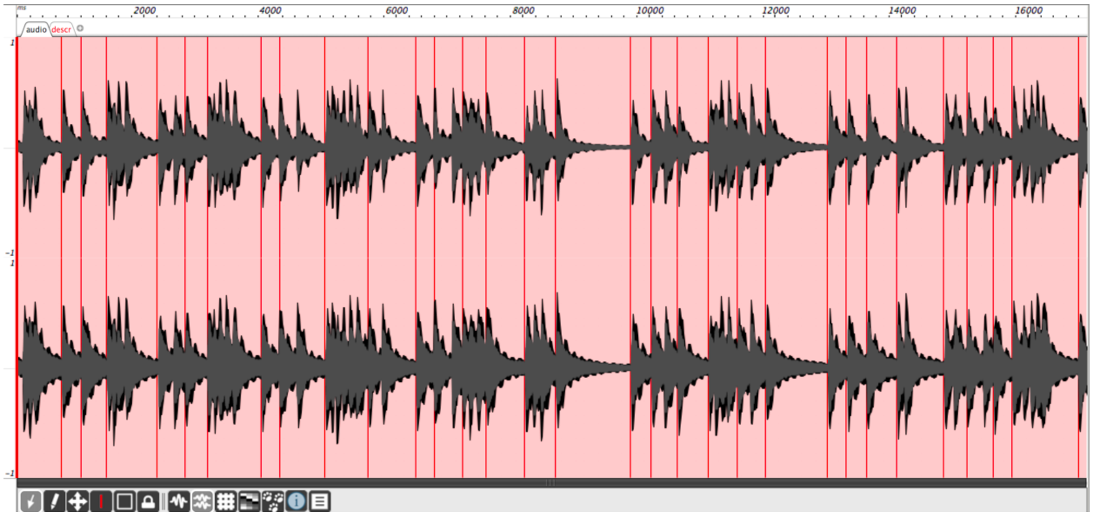


Figure 20: Mubu in action, a recorded sound buffer is segmented based on an on-set amplitude analysis.

5.6.2. Envelope following

I have developed a fast multi-function envelope follower in Max/MSP and Gen~ which is capable of scaling and analysis at the sample level (see *Figure 21.)*

The signal flow of the envelope follower is as follows: after the input stage the signal is routed through a multi-mode filter (offering highpass, lowpass, band-pass, and band-reject modes) with selectable frequency cutoff and Q values. Following the filter is an RMS averaging stage which averages the input across a pre-defined length of time (in milliseconds).

The signal is next routed through a smoothing stage, and then to an automatic signal scaling system which features manual and learning modes. In the included screenshot, the ‘minimum input scaling value’ is set to 0, and the ‘maximum input scaling value’ is set to 0.2. The corresponding output values are defined as 0 (minimum) and 1 (maximum). Thus, input signal values observed between 0 and 0.2 (on a 0.0-1.0 float scale) will be linearly scaled to output signals between 0.0 and 1.0.

Finally, before the final output stage is a variable linear ramp. This allows for the highlighting of the release or attack stage of a correlated gesture. For instance, if I pluck a spring, I can set a 1000ms ramp down (release) to allow a sound to continue sounding even if the acoustic spring signal has dissipated.

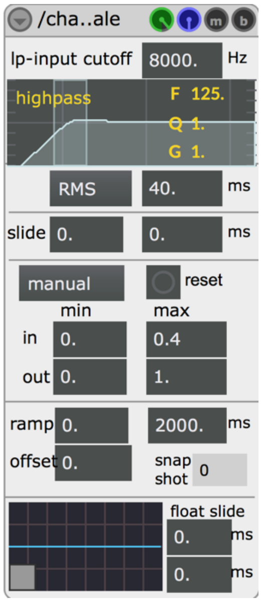
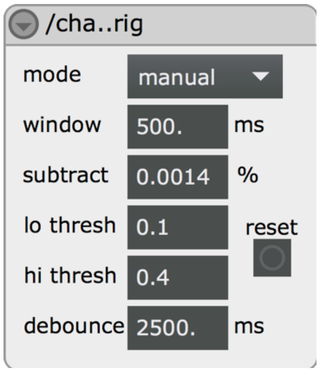

/cha..ale
lp-input cutoff 8000. Hz
highpass F 125. Q 1. G 1.
RMS 40. ms
slide 0. 0. ms
manual reset
min max
in 0. 0.4
out 0. 1.
ramp 0. 2000. ms
offset 0. snap shot 0
float slide
0. ms
0. ms

Figure 21 Envelope follower written in Max/MSP (see Appendix I).

5.6.3. Schmitt trigger

I created a specialised Schmitt trigger in order to add organised modulation of pitch, and to trigger specific events throughout performance. A Schmitt trigger “does not count a zero-crossing unless the signal goes far enough past zero. For instance, if the signal is negative, it will not count as going positive until it passes a sufficiently large positive value. It will then count as positive until it passes a large enough negative value and so on. It ignores any part of the signal between these two thresholds, in order to avoid glitches” (Pocino, 2000, p. 568).

The Schmitt trigger (see *Figure 22)* receives an input carabiner microphone signal, and has three operating modes: manual, learn, and running. In "manual" mode, the user inputs a maximum threshold above which a trigger will be sent, and a debounce value in milliseconds which only outputs one trigger across the inputted millisecond time window. In "learn" mode, the performer can create a sound or gesture which will automatically set the threshold value to the highest peak amplitude observed. In "running" mode, the user sets a "window" value in milliseconds for which the threshold will constantly reset to highest peak amplitude and reset to zero at the end of the window. This mode is useful for example to extract the most significant (by measured amplitude) gesture across a time range, and for generating pluck triggers on incoming material of varying amplitudes.



mode manual
window 500. ms
subtract 0.0014 %
lo thresh 0.1
hi thresh 0.4
debounce 2500. ms

Figure 22: Schmitt trigger written in Max/MSP (see Appendix I).

5.6.4. Algorithm

I wanted to bind algorithmic compositional systems to the physical properties of my instrument. I explored a variety of compositional ideas for numerical transformation proposed by American composer Tom Johnson in his book *Self-Similar Melodies* (1996). While Johnson's algorithms were designed for pen and paper applications, they are very simple to implement in software. The primary algorithm used in this performance is referred to by Johnson as "Transforming Ones and Zeros" (Johnson, 1996, p. 73).

This algorithm is a very simple find and replace algorithm. In the printed example below, we begin with an origin sequence such as "100". We also create a "zero" sequence and a "one" sequence. We then replace each character in the origin with the corresponding "zero" or "one" sequence (Johnson, 1996, p. 73-82).

Origin: 100

Seq0: 010

Seq1: 110

First iteration:

110 010 010

Second iteration:

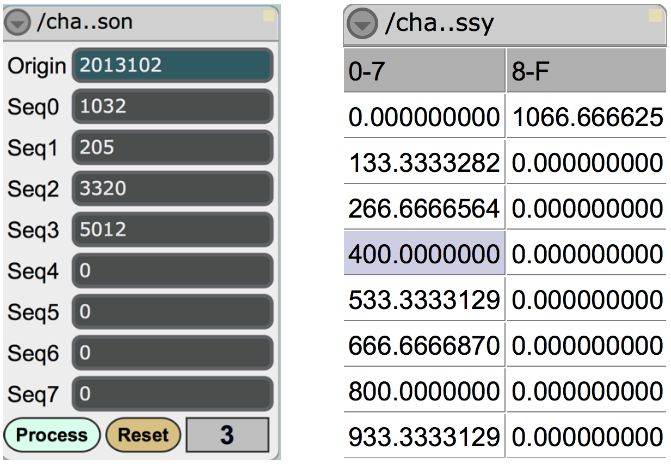
110 110 010 010 110 010 010 010

Third iteration:

110 110 010 110 110 010 010 110 010 010 110 010 110 110 010 010 110 010 010 110 010 010 110 010

. . . etc.

My version of the algorithm has been modified to operate with up to eight sequence values (Seq0-Seq7), as opposed to the two sequence values used in Johnson's original algorithm. I use the Schmitt trigger to recognise (by amplitude measurement) significant gestures, which then step through stages of the Johnson number transformer, at each stage triggering a pitch from a nine-tone equal temperament scale stored inside of an editable data container (see *Figure 23.)*



Origin 2013102
Seq0 1032
Seq1 205
Seq2 3320
Seq3 5012
Seq4 0
Seq5 0
Seq6 0
Seq7 0

0-7	8-F
0.000000000	1066.666625
133.3333282	0.000000000
266.6666564	0.000000000
400.0000000	0.000000000
533.3333129	0.000000000
666.6666870	0.000000000
800.0000000	0.000000000
933.3333129	0.000000000

Figure 23 Tom Johnson inspired number transformer and editable data container (see Appendix I).

5.6.5. Sampler

Selected pitches are received from the Johnson algorithm and processed by a VST sampler instrument, TX16Wx (CWITEC, 2018). The instrument is based off the functionality of the Yamaha TX16W sampler instrument from 1987, but upgraded in terms of interface and sample format support.

I made a series of recordings of custom Reaktor (Native Instruments, 2018) instruments, and produced from those multi-sample recordings which were loaded into the TX16Wx sampler. Frequently, the various internal processing effects of the instrument are used to further transform the sampled recordings in response to gestural activity.

5.6.6. Side-chain compression

In conceiving the sonic space of *Coil Cascade*, I had imagined reverberant metallic springs fading in and out of each gesture, a true fusion of the digital and the material, and warbling digital textures that would fade out to the hissing of the assemblage of taught springs. I wanted to achieve this effect in unison with the movement of the spring in space.

One method I adopted to achieve this effect is side-chain compression. With the acoustic spring signals patched to the main input of a VST compressor, and the digital sound from the sampler and MuBu instruments wired into the side-chain input, multiple kinds of signal morphing in the amplitude domain are possible. With a very slow attack sound played by the sampler, and low threshold (-80db) and high ratio set (8:1) on the compressor, a gesture performed on a spring will sound entirely acoustic until the side-chain input signal increases in amplitude and the acoustic sounds fade to the back in tandem with the digital sound appearing in focus.

5.6.7. Associated software library in Max/MSP

A major component of this work is an associated software library built in Max/MSP which consists of individual modules which can be quickly repurposed in a variety of performance and installation contexts (see *Appendix I)*. The library is composed of 18 individual modules capable of performing a wide variety of tasks: envelope followers, compositional algorithms, trigger driven data containers, a concatenative synthesis engine, signal filters, envelope generators, and scaling tools. The library is open-source, and available on my GitHub repository[4].

Each module in the library is wrapped with tools from the Jamoma (Jamoma, 2018) framework, allowing every individual parameter of an assembled instrument to also have an associated OSC parameter name and value which is automatically discovered (and available to map or process) by other objects within a patch. As individual modules are self-contained and reconfigurable, they have already found their way into other digital art projects including *Tangible Flux* (Navab, 2018), and in various experimental instruments built as part of the circus arts residency CirK 2.0 I participated in in 2017 (described in Chapter 7.1.1).

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[4] Available at: https://github.com/petervanhaaften/PVH-maxlib

6. Spiel

6.1. Concept

6.1.1. Inspiration

Spiel is a collaborative work between Michael Montanaro and myself. I was responsible for the creative direction, composition, sound, programming, and electronics. Montanaro was also responsible for creative direction, and the visual design of the instrument.

In tandem with *Coil Cascade*, *Spiel* serves as a case study in harnessing material modulation for compositional purposes. How can mouth movement be exploited to guide algorithmic process and sound transformation in performance? *Spiel* is an in-situ performance for prepared mouth: a multi-disciplinary work which encompasses elements of contemporary dance, theatre, and solo electroacoustic live performance. It is a performance for casual social interactions, in which the performer has a great deal to say, but due to an error she is unable to speak with her own voice. She needs to collect conversations and uses those voices to communicate back to the audience utilizing her mechanically augmented vocal tract (see *figure 24*).

The story of *Spiel* is left purposefully ambiguous to highlight the primary performing material: the mouth, and its extraordinary natural capability to perform as physical sound processor. In Spiel, the physical transformations of the mouth's topological figure are mechanically and numerically enhanced, allowing it to act as both compositional agent and active computational processor. In performance, the audience perceives no speakers, cables, wires, or buttons: all sound emanates from and is transformed by the mouth.

Spiel attempts to reveal the concealed cadence in conversation. The natural affordances of the mouth are augmented by the wearable steel and brass instrument and enable the performer to develop her own manner of dialogue[5] (a communication of note) in performance. On verbal communication, Lefebvre (Lefebvre, 1992/2016) is dubious of its honesty: "Communication certainly exists, has become fluent, instantaneous, banal and superficial – not touching the everyday, the kernel of banality become product and commodity, an insipid flow flooding the age. Communication devalues dialogue to the point of its being forgotten" (Lefebvre, 1992/2016, p. 58). *Spiel* attempts to disassemble and inspect the natural rhythmicity of dialogue and spoken

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[5] Dialogue, as it is expressed in Platonian dialogues : *Euthyphro, Phaedo*, *Theatetetus*, *The Republic*, and elsewhere.

word and to uncover its ingrained subtleties and essence of structure. Audience words collected in performance are first repeated verbatim then, through a progressive process of continuous sound transformations mapped to the performer's movement and stripped of their semantic meaning.

During many rehearsals and experiments with two different performers (Greg Salinger and Nien Tzu Weng), we devised a set of techniques and gestures to create audience engagement. The performer collects material by approaching audience members in conversation, at first only silently mouthing words. The performer then leans in with her hand held over her ear, gesturally encouraging the subject to feed sound into the instrument. If the subject speaks too quietly, or appears not to understand the gesture, the performer will integrate new elements that motivate the audience to speak at an appropriate level into the instrument. When the performer tires of her interaction, she can dramatically cut into the next nearest group of audience members, or alternatively find a chair or staircase to sit on and privately process voices until she discovers a new audience unaware of the situation they have stumbled into.

Figure 24: The mechanically augmented vocal tract instrument employed in Spiel.

6.1.2. Performance material

Spiel plays with a commonly experienced form of synaesthesia first documented by Harry McGurk and John MacDonald in the 1976 *Nature* article "Hearing Lips and Seeing Voices" (McGurk and MacDonald, 1976). While verbal communication frequently occurs in situations where the listener can both see and hear the speaker, speech perception has long been considered a purely auditory process. In McGurk's seminal study, he demonstrated that the visual component of speech has significant influence. The study was conducted utilizing video overdubbing, whereby an audio recording of a woman repeating the syllable [ba] was dubbed behind a video recording of her mouth the syllable [ga]. When the overdubbed video was presented to study participants, a majority of respondents reported hearing a third syllable [da], yet when presented separately with either the untreated film, the audio recording, or video image, participants correctly reported the syllables as [ba] or [ga] (McGurk and MacDonald, 1976).

This neurological phenomenon serves as a fundamental theoretical underpinning of the *Spiel* performance. Through many practical experiments, we discovered that if the performer could capture harmonically rich voice recordings, she would be able to impart clearly perceivable new formant inflections and words on top of the audience voices. At times, audiences will perceive clear words, re-processed formants, or unintended ghost syllables and words resulting from the McGurk effect. This component of *hallucination* feeds into every aspect of *Spiel* in performance. A great deal of effort was put forward to hide the sensors and associated electronic components from the audience, in order to further instill the sense that the sound processing is performed not by a computer with digital software, but merely by the movement of the tongue and lips.

6.1.3. The Sound matter

The sound matter in *Spiel* is derived from voices live recorded by an embedded electret ear microphone. Voices are processed by a digital instrument (described in Chapter 6.5.1) and emitted into the mouth via a ¼ inch bronze tube which is connected to a hidden compression driver. This unusual mouth speaker apparatus has considerable effect on the sound of the instrument, giving it a somewhat low-fidelity quality, at times very smooth and lyrical, and at others digital, harsh, and cutting.

Recorded voices are processed by one of 12 different digital sound processes which are randomly cycled, after every 8th-12th playback button press. When the performer engages the instrument, she is able to modulate parameters of the digital instrument through chin movement, producing extensive sound transformations on the recorded voice. Crucially, repeated deformations of the mouth topology imparts timbre modulation by (physical) formant shaping. At the beginning of the performance, the performer will reveal a few select words to let the audience know she has collected their voice. As the performance progresses, she will improvise many iterations of sound transformation through chin and mouth movement, before finally returning to a clear sounding recording and moving on to collect new material.

6.2. Form

6.2.1. Composition structure

The compositional structure of Spiel is variable and highly dependent on the interactions that occur within the performance space. From the outset, I had determined that the performance would take place in casual social situations. In particular I was curious to produce the performance in various social and spatial settings: during concert intermissions, in art galleries, and across the grounds of digital art exhibitions and festivals.

Each performance, and performer, introduces new ideas into the flow of performance. The first performances were very conversational, whereas more recent performances, in part aided by a vastly improved instrument, appear much more abstract as the current performer gesturally improvises communication to the audience. The composition is determined firmly by the technical limitations of the instrument, and the social and spatial contexts in which the performance unfolds.

6.2.2. Visual design

The visual design of the *Spiel* mask was inspired by images of various early 20th century dentistry devices. From the start, our intention was to create a mask which would highlight yet not impede the movement of the mouth. Designed in collaboration with designer Tatev Yesayan, we sought to create a wearable instrument that is both functional and ornamental, and went through two different design revisions before arriving at the final instrument.

The mask was designed so that it could be disassembled, if individual parts need to be replaced or modified. The jaw and chin pieces have been designed in three different sizes, so that they could fit a variety of performers. Small screws hold the individual parts together to form the complete mask, leaving a loose connection at the back of the jaw to allow the performer complete gestural fluidity. Wires for mask sensors are folded inside a hidden track underneath, invisible to the audience (Yesayan, 2018). For the final version of the mask, I worked with a local jeweller to cast a ¼ inch tube from bronze, which perfectly fits the jawline of the current performer, and feeds sound from a compression driver stored in a backpack directly into her oral cavity for sound processing.

6.3. Mask construction

The first and final *Spiel* masks are quite similar. The structural design remains largely the same and was built primarily from hammered steel and brass. Design files drawn in a CAD (computer assisted drawing) application were cut into a set of individual steel and brass bars, which were later hammered and finally assembled with screws. An earpiece was harvested from the lens of a circa 1960's Leica manual camera, and used to hide a super-cardioid electret microphone for conversation recording. A thin folded piece of steel was mounted under the chin of the mask to hide an embedded accelerometer and gyro sensor, both necessary to track mouth and head movement for sound processing.

The first instrument prototype had a brass bar mounted to the chin which inserted a tiny electret speaker with attached light emitting diode into the mouth (see *Figure 25*). The speaker was moderately loud and easily perceivable by an audience if mounted externally to the oral cavity in a resonating chamber (for example, a tiny cardboard box), but it was also dampened extensively by the wet flesh of the mouth. The sound was still perceptible, and the performance was adjusted to deal with the limitations of the instrument. The early performances were intimate, with the performer revealing the audiences transformed words directly back into the ear of the audience.

The second instrument was redesigned with a 40W 16ohm compression driver mounted inside of a backpack. A custom machined threaded aluminum tube holder was screwed on top of the driver, allowing sound to exit the driver through a ¼" plastic tube. The tube runs from the driver and out of the backpack into one side of the mask, from where it is fed into a casted bronze tube which finally passes sound into the mouth. While the compression driver is amplified below its rated specification, with the equivalent of a 25W amplifier at 16ohm, the level of amplitude in the new instrument is a great improvement over that of its predecessor. The amplifier is powered by two 1.3AH sealed lead acid batteries wired in series to provide 24-26V of power. The batteries sit in the front pocket of the backpack.

The first *Spiel* instrument prototype (*Figure 25*), which embedded piezoelectric speakers inside of the oral cavity.

Figure 25: The original instrument, with speaker in mouth.

The final *Spiel* instrument (*Figure 26*), which feeds sound directly into the mouth from a ¼ inch casted bronze tube.

Figure 26: The final instrument, with casted bronze tube.

6.4. Electronics construction

6.4.1. A mobile music platform

The *Spiel* instrument includes a fully portable music performance platform, complete with the ability to record, process, and perform sound. It is a simplified system designed to be performed by a non-specialist. Only a few controls are delegated to the performer. The performer is capable of recording audio (left hand button push), playing back audio (right hand button push), and processing audio in real-time through gestural activity (accelerometer under chin, and material formant movement).

The system is battery operated and capable of running uninterrupted for about thirty minutes before both the compression driver amplifier and microphone pre-amplifier need to have their batteries changed. Apart from the wearable mask, the whole project resides inside of a small backpack with a total weight of around 15lbs, which is acceptable for the performer to wear even for up to six hours, with regular breaks.

6.4.2. Chin accelerometer

A metal slot and piece of foam positions an accelerometer under the chin. Using the Madgwick Arduino library ("MadgwickAHRS", 2016), I am able to get a reading for pitch, roll, yaw, and velocity. Messages are routed from the Arduino to the Raspberry Pio computer over OSC USB serial. The accelerometer wires run underneath the mask in a hidden track and exit at the jaw on the performer's right hand side, hidden by her hair, and run down her shirt and into the backpack.

6.4.3. In-ear microphone

A small super cardioid electret microphone is hidden beneath a brass earpiece scavenged from an old manual film camera. The super cardioid microphone pattern was chosen with the intention of limiting interference of voices and sounds from across the room, capturing primarily nearby voices in a tight pattern. The pre-amp used for the microphone is a MAX4466 breakout board from Sparkfun Electronics (Sparkfun, 2018). The microphone power and signal cables run down the performers back and into the backpack and the power cable is fed three volts from two AA batteries. The microphone signal output plugs into the Raspberry Pi soundcard.

6.4.4. Hand switches

Miniature buttons are attached with surgical tape to the performers hand, and she secretly presses them with her thumbs to record (left hand) or play back (right hand) audio. The switches are detachable from a cable that feeds into her sleeve, as the buttons have a tendency to fall off after several hours of performance, and may need to be replaced in performance. The wires for the switches feed through the arms of her shirt, and out into the backpack where they are read by the same Arduino microcontroller, and fed as OSC messages into the Raspberry Pi computer.

6.4.5. Computer box

A steel box inside of the performer's backpack holds most of the project electronics. Inside of the box is a 100W amplifier, measured at four ohms, which feeds roughly 25W to the 40W 16 ohm compression driver. The box includes also a Raspbery Pi 3 computer with an attached stereo sound card (Audio Injector, 2018), and an Arduino microcontroller. In total, the box has a single USB input for the various sensors, two cables which connect to the amplifier batteries, an audio input for the microphone, and an amplifier output which feeds into the compression driver.

6.4.6. Compression driver

Similar to a classic talk box guitar processor, the *Spiel* instrument drives a compression driver (see *Figure 27)* to feed sound through a rigid plastic tube into the mouth. After some experimentation with three different models of drivers, I settled on a 40W 16ohm compression driver manufactured by MCM electronics (Newark, 2018). Most modern compression drivers are available only as high frequency drivers, however this particular model is rated between 100hz and 8khz which is acceptable to process voice recordings which are already highly limited in frequency bandwidth.

This particular compression driver has one unfortunate drawback in that it looks alarmingly similar to an explosive device. This has been considered quite problematic by airport security personnel.

Figure 27: MCM 40W 16OHM compression driver, used to feed sound into tube.

6.4.7. Batteries

Three separate types of batteries are employed to power the wearable *Spiel* instrument. For the compression driver amplifier, two 12V 1.3AH rated batteries are wired in series to provide up to 26V when freshly charged. Two AA batteries are used to power the microphone preamp, to avoid running the sensitive electret element from the Raspberry Pi USB power which would induce noise. The amplifier and microphone batteries are changed every thirty minutes. Lastly, a 2A USB power bank provides all the power necessary to run the Raspberry Pi computer and Arduino microcontroller for at least 8 hours.

6.5. The software

6.5.1. The digital instrument

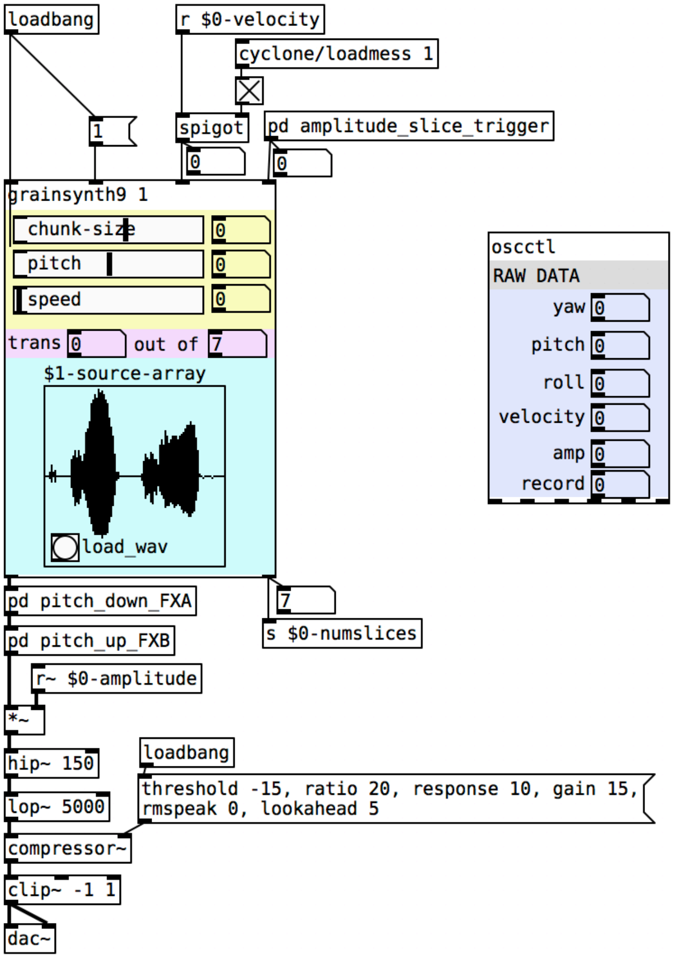

Figure 28: The digital Pure Data instrument, running on embedded backpack computer.

For the digital instrument of *Spiel* (see *Figure 28)*, I attempted to keep things very simple. As the performers have been neither sound artists, musicians, nor audio enthusiasts, it was important to have many decisions taken by the software, allowing the performer to focus on recording and transforming voices. Thus, the performer is able to only record, play, and modulate voices (via chin and mouth movement).

The digital instrument was written in Pure Data and is centred around a looping granular buffer recorder and playback module which allows for independent pitch and time shifting. The buffer module features FFT based transient analysis which automatically finds places within a recording where a word (beginning with a transient sound) is spoken, so that when played back the instrument will start with a word, rather than a break of silence. Pairs of 12 possible digital processors are randomly cycled after every 8th-12th playback button press. Pitch and time shifting are mapped to the velocity of chin movement as derived from the embedded accelerometer, while a single parameter of each of the 12 potential sound processors is available to be controlled by accelerometer pitch. Two effects are usable at one time: with the chin horizontally level, no sound processing will occur, while if the chin is tilted up, it will engage and modulate one process, and if the chin is tilted down, it will engage and modulate another.

The 12 digital signal processors available for random selection on the instrument are as follows:

1) Buffer shuffle.
2) Comb filter.
3) Rhythmic buffer trigger variation 1.
4) Waveshaping and vibrato.
5) Rhythmic buffer trigger variation 2.
6) Granular “bubble” delay variation 1.
7) Granular filter.
8) Pitch delay.
9) Amplitude modulation, tremolo.
10) Rhythmic buffer trigger variation 3.
11) Granular “bubble” delay variation 2.
12) Granular “Buffer” delay variation 3.

Lastly, an amplitude-based audio analysis of the processed signals sends OSC messages back to the Arduino to control flickering of a small bright white LED light that sits inside of the mouth.

7. Conclusion

7.1. Related future projects

7.1.1. Juggling clubs.

During this research, I partook in a two-week long residency at l'Ecole Nationale de Cirque with circus artist Naël Jammal, and my frequent collaborators from the *Topological Media Lab* Navid Navab, and Evan Montpellier.

Throughout the residency, we attempted to sonify various types of performative circus activity, including Chinese hoop dancing, hand standing, and by far the most successful of the set, juggling. Unbeknownst to the sound artists, juggling has its own form of rhythmic notation to determine the number of clubs that may be thrown for any given maximum height of toss. This notation appears highly musical. My collaborator Navid Navab and I intend to cowrite a 20-minute juggling performance for two juggling performers in the near future.

A short video of some of our early sonified juggling club experiments is noted in Appendix IV. The technology necessary for this performance was quite simple: a wireless accelerometer duct taped to each juggling club. The sonification is rudimentary, and mostly consists of simple sine waves. Considerable effort was undertaken so that the audience would have an auditory sense of the real-time manner in which clubs rotated in space.

7.1.2. Hyper aeolian harp.

Over many years, I have been keen to construct an aeolian harp, an instrument first developed in the ancient world (Bonner, 1970, p. 15-6). It is a kind of stringed harp which is performed entirely by the wind. My first introduction to the instrument came some 12 years ago, in reading Henry David Thoreau's *Walden* (2004). It was Thoreau's favorite instrument, and usually sat idly in a window frame of the cottage he built on Walden Pond in Massachusetts, consistently filling his small home with sonorous ambient music performed by wind.

> *"Yet I experienced sometimes that the most sweet and tender, the most innocent and encouraging society may be found in any natural object, even for the poor misanthrope and most melancholy man. There can be no very black melancholy to him who lives in the midst of Nature and has his senses still. There was never yet such a storm*

> *but it was Æolian music to a healthy and innocent ear. Nothing can rightly compel a simple and brave man to a vulgar sadness."* (Thoreau, 2004, p. 131)

Aeolian Harps can take on many diverse forms, from the small window box of Thoreau's day, to much larger structures constructed from steel in more recent times. Based on previous work by Athanasius Kircher, William Jones wrote in 1781, as cited in Stephen Bonner's *The Aeolian Harp Volume 4: The Acoustics of the Aeolian Harp Supplement* (1974), that "upon the whole, the Eolian harp may be considered an air-prism, for the physical separation of musical sounds" (Bonner, 1974, p. 15). Jones suggests that "music is in air as colours are in light" (p. 15), and so as light is able to produce multiple colours by inflection and refraction, so too is wind able to produce multiple pitches across a string. Just as light is unable to produce any particular colour except by aid of an intermediary material, neither is wind able to reveal its sonorous qualities except by way of a medium which obstructs its path (p. 15-7). The aeolian harp offers exactly this, and even a monochord (single-stringed) aeolian harp is capable of producing multiple tones, by way of the wind modulating the movement of different parts of the string independently (p. 13).

Relevant to my studies of revealing rhythms in everyday situations, material computation, and the mapping of sound to gesture, the aeolian harp is an ideal platform to explore further with these ideas. I intend to approach this work in a minimalist fashion, a miniature computer installed inside of an elegant wooden box, and piezo-electric microphones tracking the acoustic movement of the spring in space. Speakers or transducers will be hidden inside of the box to produce an instrument capable of composing infinite droning ambient material from subtle string inflections diffused by the movement of air.

7.2. Critiques and changes for future

7.2.1. Coil Cascade

In the *Coil Cascade* performance, there are still some elements to be finalized before it is entirely ready to be presented in a professional context. Primarily, I intend to remove the scraping gesture from the beginning of the first movement, and replace it with bowing. The original "spring clipping" section was not working, and I am currently writing a new section of music which fully benefits from the newly added carabiner button clips which allow me to trigger new sounds and compositional fragments every time I remove or add a spring to the structure.

Likewise, the third movement needs to be rethought: in this section I intend to diverge from the previous movements which tend to rely directly on the gesture of the performer and the spring to drive the composition. Instead I plan to write a new movement which allows the morphology of the sound to modify the physical gesture of the spring movement. Instead of hanging and subsequently controlling each spring individually with electromagnets, I will hang all springs at once at the beginning of the third movement, and then fade the light to black. The springs will be separated visually in two separate panels (front and back), with the back panel first being lit with single pulses of light with a very long decay, which are correlated to the movement of a slow fixed electronic composition. The fixed composition will play on top of sizzling digital textures which are to be generated by the movement of the springs, and sonified with the concatenative synthesis engine. The back wall will play for up to 90 seconds, before the front wall is also brought in at a contrasting rate. I will walk off stage and allow the two walls of springs to perform the rest of the composition, culminating in strobing spring images which appear to move forwards and backwards in time. After this, I will walk back on stage to finish the performance by connecting the front sliding spring and performing one final pull on the spring.

Beyond these additions, the lighting needs to be rethought. I will be introducing lighting elements which subtly respond to the performed sound as it is fed out of the system.

7.2.2. Spiel

Spiel was heavily rebuilt over the summer of 2018 in preparation for an extended performance at *Ars Electronica* in Linz. It was performed for 24 hours across four days throughout the many diverse spaces of *PostCity* complex (van Haaften & Montanaro, 2018). New performances are on the horizon, and while the performative elements are very strong, and the instrument is stable, robust, and expressive, I intend to make some small adjustments to the electronic part of the work. Firstly, the current battery situation is less than ideal, lasting for only around 30 minutes before they are depleted. I intend to replace the sealed lead acid batteries with an electric bicycle lithium-ion type battery. This change will also provide a higher voltage (36V, vs 24V), which will enable me to utilize a better amplifier for higher fidelity sound output. As well, the ergonomics of the current sling-backpack are not ideal, as the current performer weighs only ~100lbs, and the contents of the backpack reach close to 20lbs. So, a backpack with better support, but that still maintains a unique aesthetic, needs to be sourced to proceed for further extended multi-day performances.

Lastly, I have considerable interest in adding two more performers to the work, as there is great potential of having multiple *Spiel* performers collecting voices and sounds from the environment, and then letting the performers interact with each other. This would introduce a vibrant new element and can contribute entirely new elements into the work with performers passing messages between each other, and back to the audience. However due to the costs for festivals and art organizations of supporting multiple performers, producing many new copies of the instrument for performance and backup, and the complications of setting up so many different performers and keeping all of their batteries charged and computers online at once, this would be a complex process.

7.3. Towards a unified multi-modal gesture sound algorithm influenced performance practice.

Considering the above description of my two primary works during this master's degree, it should be clear that I am interested in unifying: gesture, sound, and algorithms. The approach I have taken should be understood as an attempt to formulate an algorithmic matter *in spirit*. Indeed, since it is still at present (at least to the best of my abilities) impossible to re-organize matter at the atomic level, there is only so far one can go to travel along this road. I endeavoured to have the key performative elements in both creations adopt my methodology throughout.

During the composition of these works, I have developed conceptual and technical tools that have enabled me to move from a practice based largely in *representation*, to a practice formulated in *performance*. I have extensively researched and employed techniques to control and model sound independent from the computer and traditional sound transformation interfaces (knobs, buttons, and screens). I have taken particular care to unravel what is significant about gesture, and how I can effectively integrate gesture as an essential performative function in my work. The conceptual development in my practice, particularly as it related to the question of gesture, has been concretely aided by collaboration on works primarily with my director of research Nicolas Bernier, choreographer and the director of the *Topological Media Lab* Michael Montanaro, and the two performers of *Spiel*: Nien Tzu Weng (current), and Greg Salinger (former).

My research-creation has been a very personal journey in music, sound, and performance. The way in which music, sound, and performance can shape human engagement with the physical world has been an essential inspiration to my approach and will serve as a fundamental conceptual thread for my future creations. Throughout this period, I have sought to move my practice in new (to me) directions, and the skills I have developed along the way will be extended and supplemented further in all my future projects. Likewise, the software library produced as part of this research, and simple sensor-based systems and electronically controllable physical actuators will aid me considerably in continuing along this path.

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Appendix I Software library

Across the research-creation process of *Coil Cascade*, a custom library of interoperable tools for the Max/MSP environment was developed. Each object has been wrapped in the Jamoma framework (“Jamoma - Modular Patching and Programming for Realtime Media”), which allows for ramping preset control of all Jamoma wrapped objects at once, and provides an automatically generated network accessible OSC address for each parameter of every tool implemented in a patch.

Various gesture-sound mapping and sound generating techniques have been implemented as separate individual modules, allowing for the rapid prototyping and creation of entirely new instruments with various module arrangements. The entire collection has been published as PVH-maxlib, an open-source (GPLv3) toolset available on Github[6]. A selection of the more unique and useful objects that form the basis of this collection are described below.

pvh.banglower

Enter value A, value B and value C. On every bang input value B will be subtracted from value A and sent to output 1, until value C has been reached, at which point a bang will be sent to output 2. Used in *Coil Cascade* to dynamically lower amplitude of performed rhythm samples at defined rates, as mapped to the natural resonant frequency of the spring.

pvh.cents2hz

Converts pitch in cents to pitch in hertz, with a defined starting frequency. Used in *Coil Cascade* to transform scale values stored as cents in the pvh.messy object into hertz values, which are then converted into floating point MIDI values.

pvh.complexosc~

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[6] https://github.com/petervanhaaften/PVH-maxlib

A monophonic west-coast synthesis styled complex oscillator, inspired by the Buchla 259 (“259e Twisted waveform generator”, Buchla). Features frequency modulation, selectable carrier waveshape morphing from sine to saw or sine to square wave, ratio or manual modulation frequency control, added modulation noise (with low-pass filtering), wavefolder, and oversampling. Originally created for *Coil Cascade* but not actually used in performance, however it has found its way into other research-creation projects including the juggling club residency.

pvh.functiongen~

An attack-decay function generator with variable shape of each stage. Closely modelled after a single channel of the Buchla 281 quad function generator (Buchla, “281e quad function generator”). This object was created for *Coil Cascade*, but finally not used in performance, however it was also used throughout the juggling club residency.

pvh.johnson1

An algorithmic composition tool, inspired by an algorithm discovered in *Self-Similar Melodies* and titled “Transforming Ones and Zeros” (Johnson, 1996, p. 73). Johnson’s simple algorithm has been heavily expanded, and written in JavaScript to ensure timing accuracy. The algorithm was implemented across the *Coil Cascade* performance, and its operation is described in detail in Chapter 5.7.4.

pvh.lpg~

A low pass gate based on a model written in Gen~ by Parker and D’angelo and described in their paper *A Digital Model of the Buchla Lowpass-Gate* (2013). Originally created for the *Coil Cascade* performance, but not actually included in the instrument. It has been implemented across other related research-creation projects.

pvh.messy

A kind of data container, which stores floating point numbers in a 16-cell array. Individual cells can be recalled via hexadecimal input (0-F, equivalent to 0-16). Implemented across the *Coil Cascade* performance as a way to store scales.

pvh.minmax~

A signal min-max signal value finder, used internally as a part of pvh.scale~, but also useful as a separate tool. The object includes three operating modes: manual, learn, and running. In 'manual' mode, the object is bypassed, as the min and max signal values will be determined by the user. In 'learn' mode, the min and max value will be automatically determined by the incoming signal, after which the operating mode can be switched to 'manual' mode to store the values. In 'running' mode, the user enters a window value in milliseconds, and the min and max signal values will be automatically reset across the defined window of time. Used throughout the *Coil Cascade* performance for gesture-sound mapping.

pvh.rhythmgen

A simple object, which generates fixed rate messages. Three values are input by the user: clock speed (in milliseconds), length (in milliseconds), and frequency (in hz). A fixed rate clock will be generated for the length of time selected, and at every clock pulse the frequency value will be outputted. Used in *Coil Cascade* to create rhythms that are precisely mapped to the harmonic frequency of the spring.

pvh.scale~

A complex signal scaling tool written in Gen~ for sample level scaling, and used across *Coil Cascade* for gesture-sound mapping. Signals pass initially through a defined lowpass filter, to filter out the less useful higher frequency harmonic partials. The signal then passes through a multimode resonant filter with nine modes, to precisely filter the salient acoustic gesture. It then goes through an optional RMS scaling stage with windowing defined in milliseconds, followed by a slide attack and decay stage for signal smoothing. Then the signal passes through the pvh.minmax object to determine the minimum and maximum signal values, which are then scaled to a defined minimum and maximum value. Finally, the signal passes through a second adjustable slide smoothing stage, before being outputted.

pvh.schwarzmubu~

A heavily modified version of an audio mosaicing example patch by Aaron Einbond included with IRCAM's MuBu software ("IRCAM Forumnet", 2018), allowing for concatenative synthesis with on-seg analysis. This patch has been used throughout *Coil Cascade* for textural gesture-sound mapping, and is described thoroughly in Chapter 5.7.1.

pvh.trigfind~

A Schmitt trigger object, used to find acoustic gestures that pass above a given dB threshold. The user enters a debounce window value (in milliseconds), and across the debounce time window the object will search for a signal which passes above a defined 'high' dB threshold. When the dB threshold has been crossed, a trigger will be sent out, and no other triggers will be outputted until both the debounce time window has passed, and the acoustic signal has passed below a defined 'low' dB threshold, upon which the process can repeat again.

Appendix II Project Abstracts

SPIEL

Spiel is an in-situ performance for prepared mouth.

While absorbed in conversation you notice a stranger approaching. With a curious instrument affixed to their face the visitor leans in, and listens. The mouth opens, patterns of rhythm and sound emanate from within: voices recognizable as your own.

Spun out of focus, words reveal their ingrained subtleties as the collector of conversation captures the sentence but not the sentiment. Vocal exchanges are recalled and reflected. Voices are transformed by physical formant inflections, while acoustic hallucinations seem to reference what might have been said.

An étude on hearing lips and seeing voices, the performer's mechanically augmented vocal tract reshapes and filters conversational spectra into new modes of mis-communication. Spiel physically unravels the tenuous synesthetic relationship between what is seen, heard and understood.

COIL CASCADE

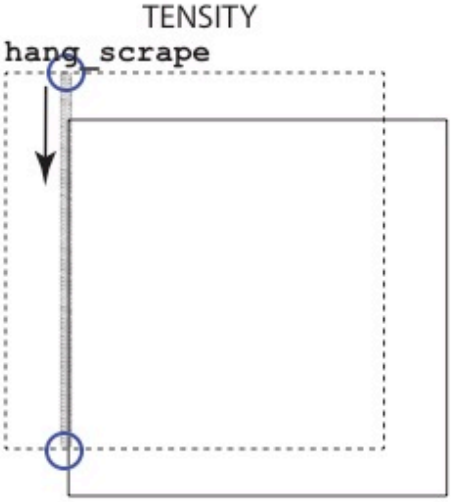
Coil Cascade is a performance for springs.

Mirroring the first electronic sound effect, Hammond's antiquated electric reverb, Coil Cascade exploits the potential of common vibrating matter as hidden musical process. Chance procedures are derived from the stochastic nature of matter itself, while sound is shaped as it undulates to harmonic spring motion.

An array of giant steel extension springs are strung in continuously morphing arrangements. Across three movements, springs are plucked, scraped, struck and bowed. At moments springs swing alone in space, activated by their own tacit harmonicity and pulsating magnetic coils. Coil Cascade is fundamentally a poetic musing on the relationships between human and non-human agency in performance.

Appendix III Coil Cascade score

1. hang_scrape



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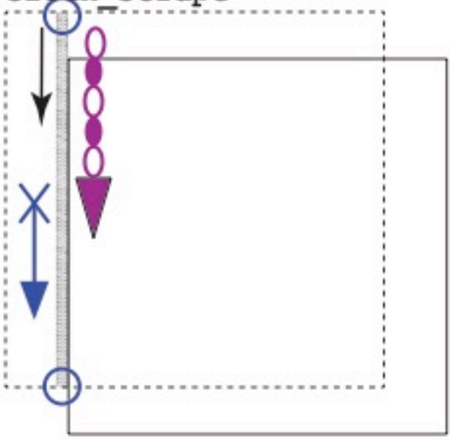
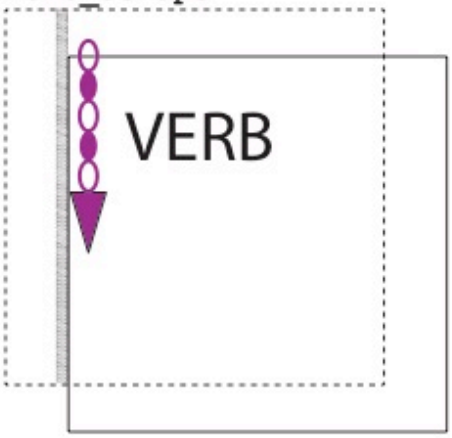
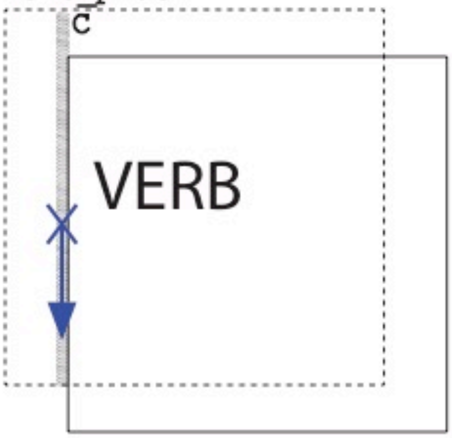


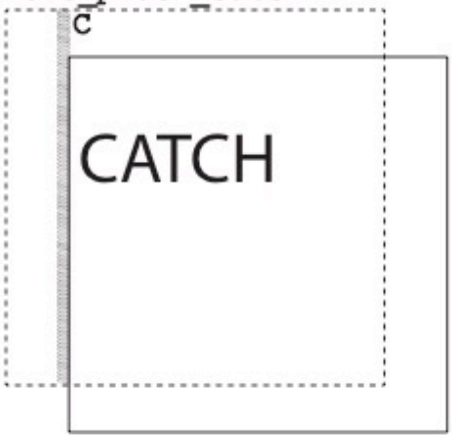
3. verb_scrape



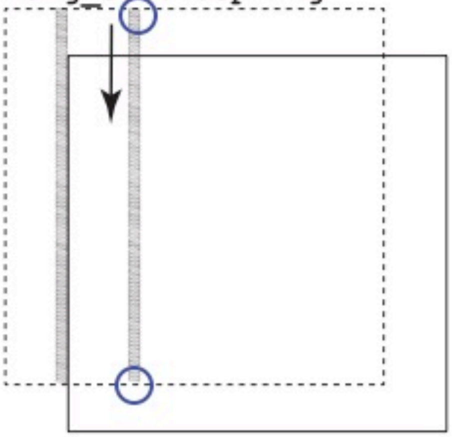
4. verb_pluck



5. verb_pluck_catch

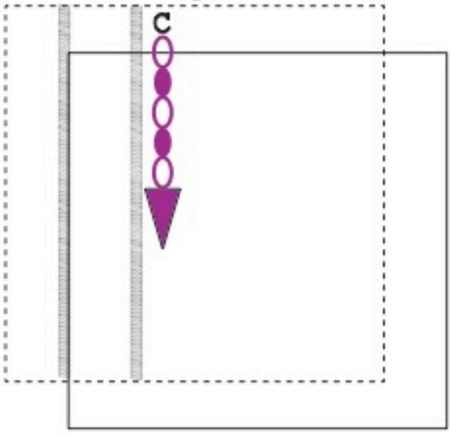


6. hang_secondspring



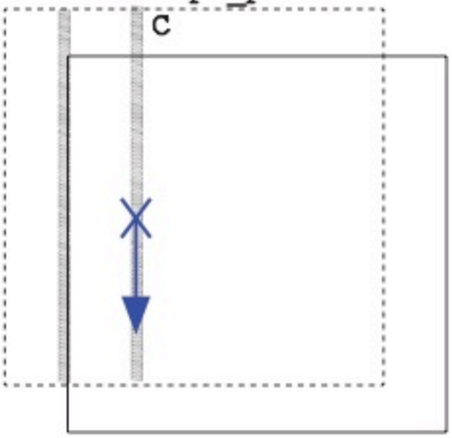
concatscrape

7.



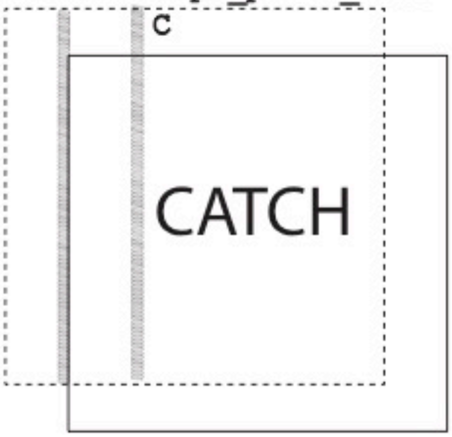
concatscrape_pluck

8.



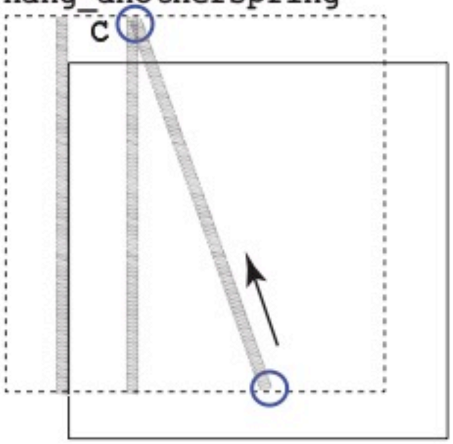
concatscrape_pluck_catch

9.



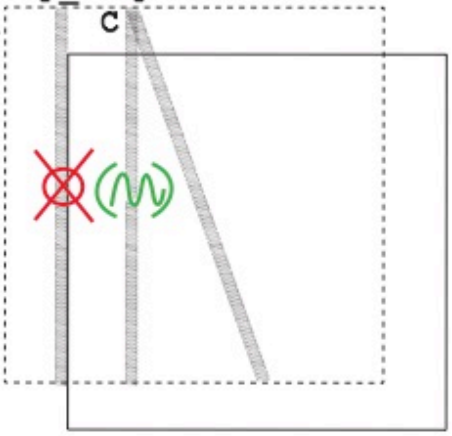
hang_anotherspring

10.



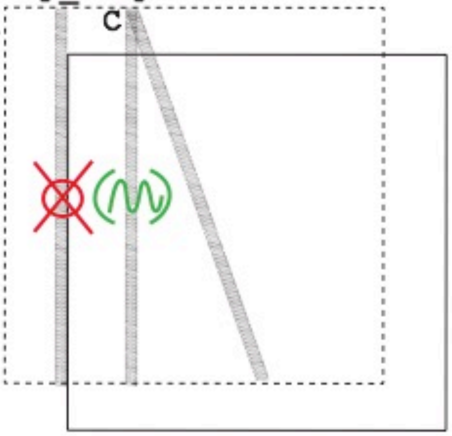
tap_slap1

11.

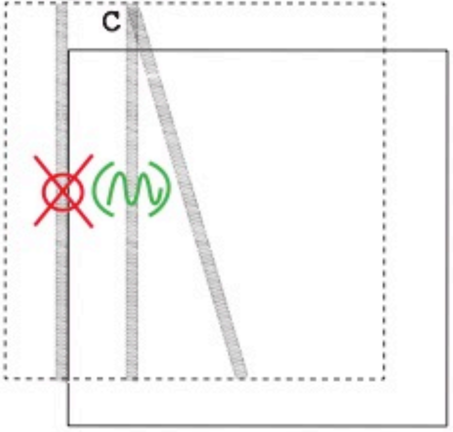


tap_slap2

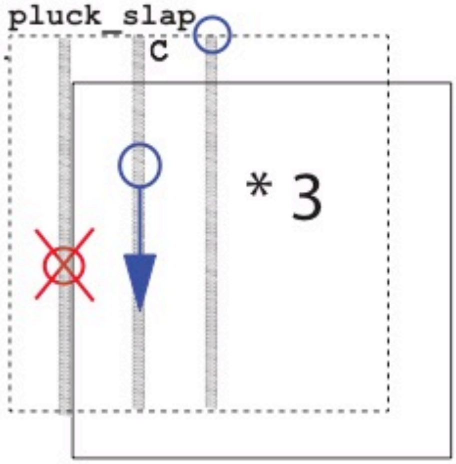
12.



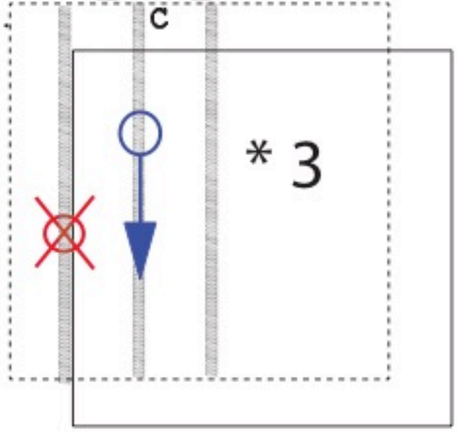
13. tap_slap3



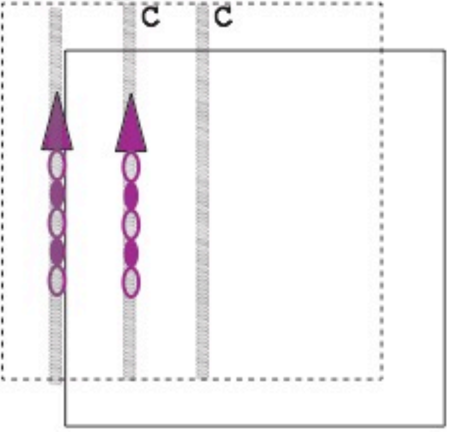
14. pluck_slap



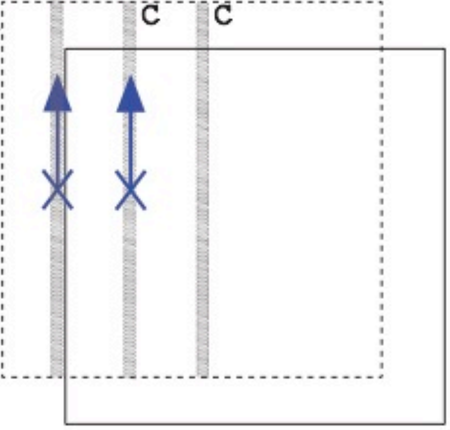
15. pluck_slap_last



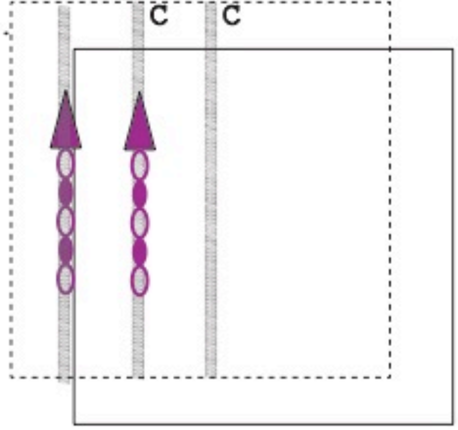
16. upward_scrape



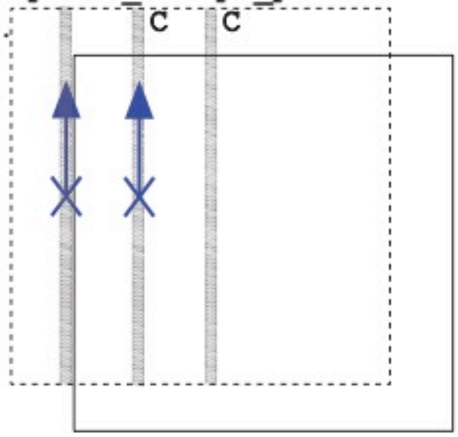
17. upward_scrape_pluck



18. upward_scrape2

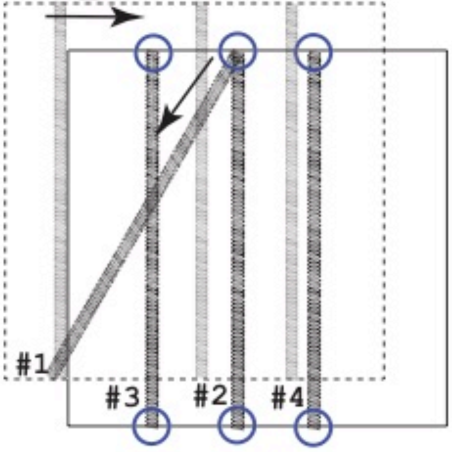


19. upward_scrape_pluck2

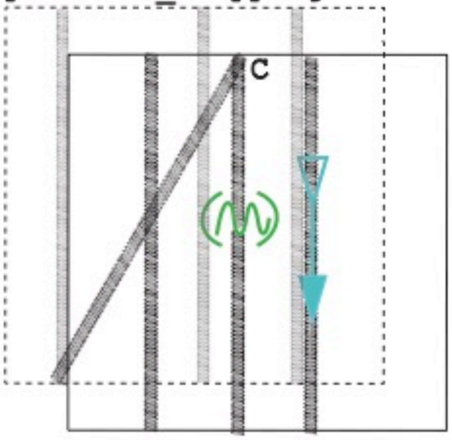


ELASTICITY

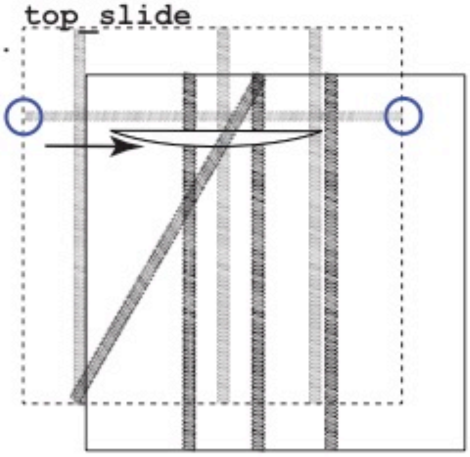
20. hang_newsprings



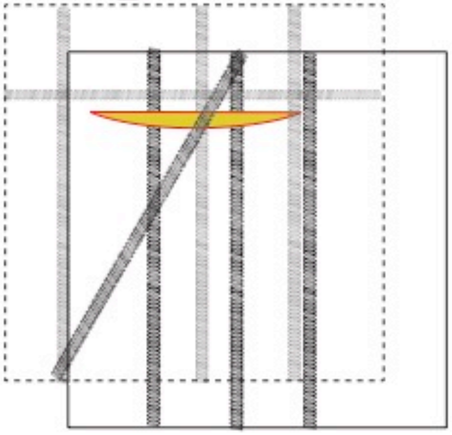
21. pulldown_slapping



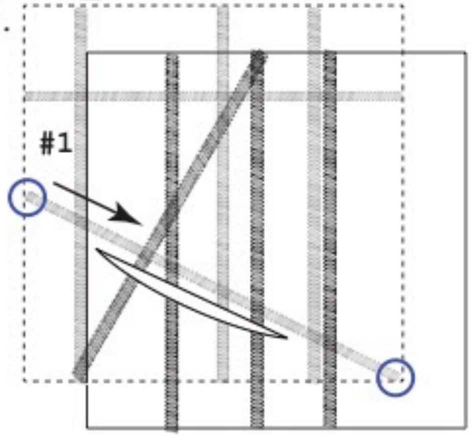
22. top_slide



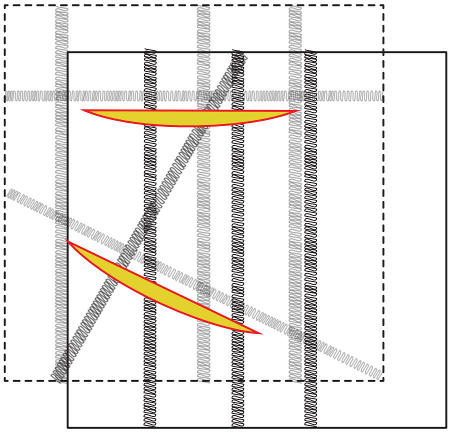
23. single_pull



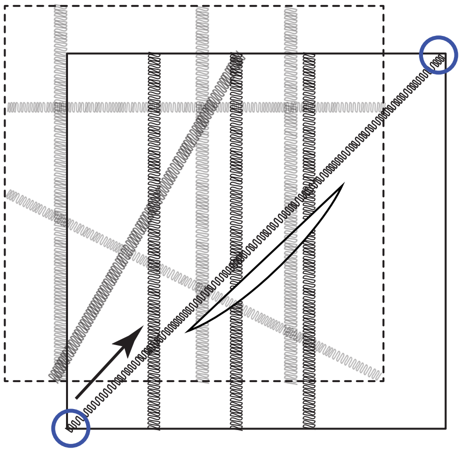
24. mid_slide



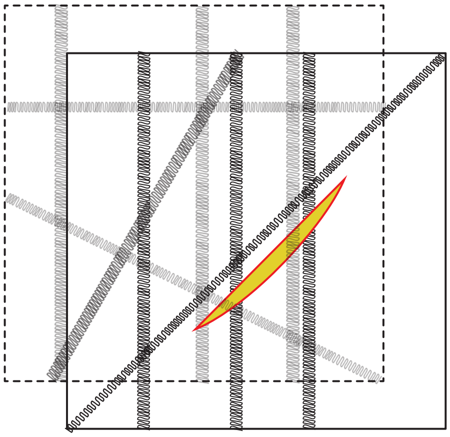
25. double_pull



26. front_slide

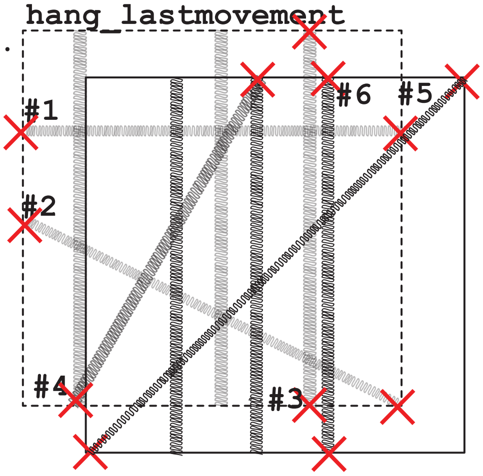


27. front_pull

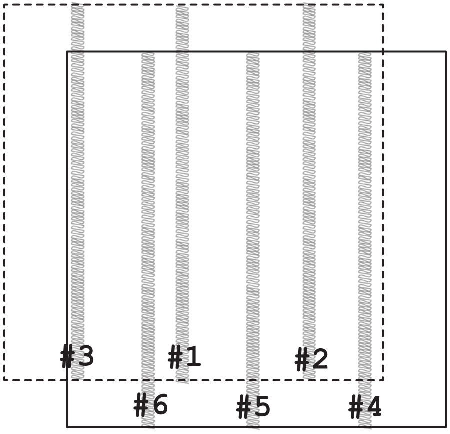


CONDUCTIVITY

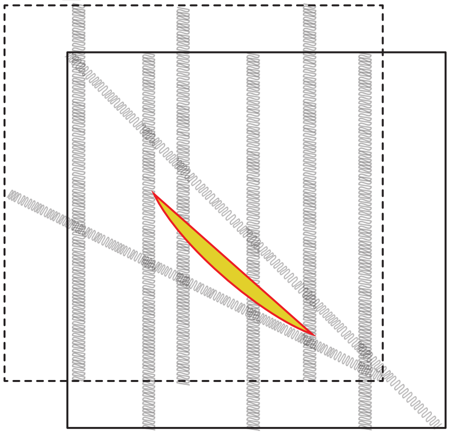
28. hang_lastmovement



29. start_lastmovement



30. end_lastmovement



31. end_performance

Appendix IV Video

1. The video documentation for *Coil Cascade* performance:

van_Haaften_Peter_2019_Coil_Cascade_Video.mp4

2. The video documentation for *Spiel* performance:

van_Haaften_Peter_2019_Spiel_Video.mp4

3. Improvised juggling with prototype juggling club instrument (see section 7.1.1), early experiment recorded simply with camera microphone at Matralab, provided merely to show performative potential of the instrument:

van_Haaften_Peter_2019_Juggling_Club_Video_01.mp4

4. Further juggling experiments at l'École nationale de cirque, primarily attempting to precisely map the rotation of the juggling club in real time to the modulator in a 2-op FM oscillator, and also a very short experiment with Chinese hoop jumping. Recorded with very draft sounds and camera microphone, merely presented to show performative potential of the instrument:

van_Haaften_Peter_2019_Juggling_Club_Video_02.mp4