UNIVERSITY OF CALIFORNIA
SANTA CRUZ

HEAVE, SWAY, SURGE

A dissertation submitted in partial satisfaction of the
requirements for the degree of

DOCTOR OF MUSICAL ARTS

in

ALGORITHMIC COMPOSITION

by

Joseph Davancens

March 2019

The Dissertation of Joseph Davancens
is approved:

Professor Benjamin Leeds Carson, Chair

Professor Larry Polansky

Professor David Evan Jones

Lori Kletzer
Vice Provost and Dean of Graduate Studies

Table of Contents

List of Figures

List of Tables

Abstract

Heave, Sway, Surge

by

Joseph Davancens

Heave, Sway, Surge (2014–19) is a musical composition for nine instruments that attempts to evoke the subjectivity of a body in motion by deploying sound-mass textures that rely on transitional acoustic states. It uses motion and force as its musical material and a system of notation in which acoustic parameters are represented vertically against horizontal time, with line segments plotting their continuous values; and shows discrete positions and configurations as tablature. The production of the score relied on a suite of software tools that formalizes musical materials, compositional processes and score structures in an object-oriented fashion, and typesets a score in PDF format for digital distribution and printing. This essay provides historical context for my aspirations with this work, discusses the modeling of instrumental performance parameters, details the notation system designed for the score, describes the architecture and development process of the software, and illustrates the decisions involved in the composition of the work.

Acknowledgments

Thank you to my parents Stephen and Amy Davancens and Brooke Chilimidos, without whose unconditional support this dissertation would not have been possible.

Part I

Text

Chapter 1

Introduction

Heave, Sway, Surge (2014–19) is a musical composition for nine instruments that attempts to evoke the subjectivity of a body in motion by deploying sound-mass textures that rely on transitional acoustic states. It uses motion and force as its musical material and a system of notation in which acoustic parameters are represented vertically against horizontal time, with line segments plotting their continuous values; and shows discrete positions and configurations as tablature. The production of the score relied on a suite of software tools that formalizes musical materials, composition processes and score structures in an object-oriented fashion, and typesets a score in PDF format.

The piece was written for the ensemble sfSound, as part of their 2015 residency at University of California, Santa Cruz. Their instrumentation centers around three woodwind players. Oboist Kyle Bruckmann, clarinetist Matt Ingalls, and saxophonist John Ingle, in both their improvisation and performances of written music, create an intricate and richly textured sound-world through multiphonics, percussive mechanical noises and other non-traditional performance practices. For this piece, I augmented their regular instrumentation (the three woodwinds, plus cello) with two nylon string guitars, violin, viola, and double bass.

I find aesthetic inspiration in natural phenomena, especially the dynamics of motion. In preparing for this work, I thought of the flow of liquids over solid objects, turbulence, vortices and eddies, interference patterns caused by colliding waves, and the way liquid suspensions mix and swirl together. I also thought about animal aviation: how animals create lift and thrust through explosive muscle movements, soaring on thermal columns, and gliding from treetops in a controlled fall. The phenomena that proved most formative for this piece are the forces that act upon a vessel in a body of water. Heave, sway and surge are three of the six degrees of freedom that a boat can experience (along with yaw, pitch and roll).

These dynamical systems involve complex interactions of matter and energy. *Heave, Sway, Surge* is an attempt to musically reflect the richness of this activity using a high density of sound events, rhythms with a short-lived or ambiguous pulse perception, and acoustically unstable instrumental sounds. The textures I sought to achieve partly similar to the sound-mass textures of Varese, Xenakis and Ligeti. Their textures are made possible by a large orchestra. I relied on a multiparametric approach to attempt this type of texture with a small ensemble. Rhythmically distinct streams of performance data are translated by the performer into physical actions that strain against conventional technique and performance practice. By isolating, extracting and scripting the components of an instrument's sound-production mechanism, surprising and beguiling sounds emerge and the potential density of events produced by the ensemble increases.

The notation used by *Heave, Sway, Surge* is prescriptive, in that it indicates the physical actions the player should perform, as opposed to descriptive notation which denotes what sounds a player should produce. It employs a combination of parametric envelopes and common practice music notation to describe movements and forces.

Woodwind parts contain three staves: one for parameters associated with breath and embouchure, one for left hand fingering, and one for right hand fingering. The guitars have a staff for each hand. Each staff has rhythms notated above or below it. The bowed strings use a single staff representing the length of the string from nut to bridge. Bowing rhythms are notated above the staff. Fingering rhythms are notated below.

Producing the score presented challenges. Drawing the score by hand or in a vector graphics program such as Adobe Illustrator was labor intensive and perhaps beyond my skills as a music engraver. Notation programs like Finale and Sibelius are unable to create the kind of parametric staves and tablatures I had in mind. One preliminary solution was be to render the rhythmic notation in Finale, import the resulting PDF into Illustrator and fill in the rest of the graphical elements. However, this approach forces one to completely commit to a global structure before producing the graphical details. Revisions on a formal scale are prohibitively time-consuming.

The optimal solution was to work with material, structure, process and notation programmatically in a single coding environment. I chose to create a software package based on Trevor Baça and Josiah Wolf Oberholtzer's Abjad software package [Baça et al., 2015]. Abjad extends the Python programming language and provides an object-oriented model of music notation. I used it to develop a command-line application that takes musical materials in the form of lists of numbers and strings, complex data structures, and generative functions and constructs a score object in memory, which, after being transformed and saved to disk as a specially formatted script, could then be rendered by the LilyPond application as a PDF file.

This wasn't the first time I had used Abjad. I was exposed to it when its creators came to UCSC in 2012 to give a presentation of their work on the system. I composed a piece called *Tundra* in 2014 using Abjad. This work, scored for snare drum and a variable number of violins, relied on Abjad to implement stochastic strategies to implement complex rhythms and microtonal pitch fields and generate a score. In contrast with the top-down approach I took with *Heave, Sway, Surge*, using various strategies to subdivide large chunks of time, I constructed the score for *Tundra* using a bottom-up approach, building up segments with small bits of material.

I knew that formalizing instrumental movement and devising a corresponding notation would be a large undertaking. As a preliminary experiment, I composed a short study for double bass (the score is included in appendix A). Recalling *Pression* by Helmut Lachenmann and Aaron Cassidy's *Second String Quartet*, I decided to represent bow and fingering motions as a sequence of line segments on a single un-ruled staff where the vertical dimension represents the length of the string. In other words, bowing and fingering position are shown as two piecewise linear functions of time. I made the following physical factors available as parameters: bow height, bow pressure, bow direction;,the index of the string to apply the bow and finger, finger height, finger pressure, and the distance between index and pinky fingers (when a double stop is required).

I encoded bow and finger position as line height. The bow line segments were colored magenta and the finger line segments were cyan. The saturation of the color indicates pressure. The string or strings on which to activate with the bow and depress with the finger are shown as letters near the line. When two strings are required, the thickness of the line represents the distance between the index and pinky fingers. Rhythms corresponding to changes in height are shown above and below the staff.

I approached the composition in both systematic and naive ways to explore the possibilities inherent in the interaction of parameters. The rhythm of the piece is based on a constant sixteenth note pulse. Changes in the direction of the bow and finger-height lines correspond to a 24- and 23-beat cycle, respectively. There are ten sections of different lengths, each with a different tempo.

To provide a general flow of how the height parameters would change over the duration of the piece, I designed constraint windows that specify minimum and maximum height [1]. The points of the constraint windows are aligned to each section boundary, meaning that constraints are constantly changing. With a constraint window in place, I determined the height of each time point by alternating between the minimum and maximum specified by the constraint window at that point. The rest of the

[1]This idea comes from [Cassidy, 2013]

parameters were decided upon more intuitively.

I typeset the empty staff, rhythmic notation, metronome markings and rehearsal letters in Finale and exported a PDF. I imported that file into Illustrator and created the rest of the graphics by hand. Many of the more intuitive composition choices were made at this point in the process. I performed an early version of the study at a concert in 2014 at the Radius Gallery in Santa Cruz, California.

In the remainder of the essay, I explain the conceptualization, planning, coding and composing stages of the production of *Heave, Sway, Surge*. In chapter two, I place the piece in a historical context and trace a genealogy between works and ideas from Cage, Brown, Ligeti, and Lachenmann.

Chapter three discusses the model of instrumental performance that lies at the core of the composition and its software application. I pay particular attention to the model's acoustical foundations and outline the musical parameters drawn from it.

In chapter four, I turn my attention to notation, describing the system I designed that attempts to efficiently convey the parameters derived from the performance model. I discuss the choices made in encoding information and how they optimize readability.

Chapter five discusses the software design and development process. I describe the package architecture and the software modeling of materials, notation and composing processes.

The final chapter describes the composition process. I look at each segment in turn and compare their approaches to form, texture, rhythm, pitch and technique.

I conclude the essay with a summary and evaluation of the production of *Heave, Sway, Surge* and it's software, and suggest future avenues of exploration.

Chapter 2

Context

2.1 John Cage's "The Ten Thousand Things"

Most instruments associated with Western art music are connected to established traditions of technique and performance practice. My work attempts to introduce novel, underutilized or undervalued sounds that can be made with these instruments to serve as the fabric of a composition. John Cage had similar preoccupations to these, among many others. He wrote a series of pieces in the mid-1950s which he referred to privately as "The Ten Thousand Things" that serves as an important precedent to the work I've done in *Heave, Sway, Surge*.

Inspired by Zen Buddhist metaphysics, Cage had a non-dualistic conception of sound, which for him expanded the space of sounds available for use in composition: a sound is a distinct aural event and there is an infinity of unique yet interconnected sounds. With the right approach, this infinite space of sound could be explored.

For Cage, rational, culturally-informed musical choice was a limiting factor in composing with an expanded sound-world. Works like *Music of Changes* for piano (1951) and *Williams Mix* for magnetic tape (1952) relied on Cage's use of chance operations to make choices regarding form, rhythm, and other musical and technological parameters.

These works relied on "charts", a set of precomposed materials, from which Cage would randomly choose using the *I Ching*. By 1954, Cage found his chart method inadequate to serve the goal of exploring an infinite sound-space, since the contents of the charts were determined in advance. However complex, novel or interesting these materials were, for Cage they were still too rational. They were limiting [Pritchett, 2009, 95].

In "The Ten Thousand Things" pieces, Cage transformed the material that served as the basis for compositions. In these works, which include *59 $\frac{1}{2}$" for a String Player* (1953), *34' 46.776" for a Pianist* (1954), *31' 57.9864" for a Pianist* (1954), *45' for a Speaker* (1954), *26' 1.499" for a String Player* (1955), and *27' 10.554" for a Percussionist* (1956), Cage categorized the possible structures of a sound-event, then determined the attributes of the sound-event at composition time using chance operations. This greatly opened the field of potential configurations.

In *59 $\frac{1}{2}$" for a String Player*, Cage determined seven kinds of sound-events. The notation clarifies the intention of these definitions. Figure 2.1 shows an excerpt from the score. There are six "staves" labeled A through F. Each stave represents a parameter space. The X axis is time and Y is a parameter value at a given time point.

In each, dots, lines and curves are drawn to represent changes in a parameter as well as to mark the existence and duration of a sound-event. The four larger staves in the middle correspond to each of the four strings of a bowed string instrument. The small staff above them represents bow pressure, and the small staff below represents various other methods of sound production.

The different categories of sound-event are described by how these marks are drawn. “Points” are simply dots on the staff, and they represent an event whose duration is relatively short and cannot be controlled by the musician. An example of this is *pizzicato*. “Lines” are events that don’t change, but whose duration can be controlled. They are drawn as a horizontal line on the staff. “Aggregates” consist of two or more simultaneous points or lines. “Angles” are sustained events that change at a constant rate, while ”curves” are sustained events whose rate of change varies. Two more event types are variations of the first two: “noise points” and “noise lines.” These are drawn on the auxiliary staff at the bottom of the system.

Above the top bowing staff (staff A), Cage drew symbols pertaining to bow technique. “H” means hair and “W” means wood; they indicate which part of the bow is to applied to the string. Three abbreviations indicate where on the string to apply the bow” “F” stands for fingerboard, “N” for normal and “B” for bridge. Cage also indicates bow direction with traditional up- and downbow marks.

Cage’s composition process involved two main steps. The first step was to determine a sequence of event types and determine their high level characteristics. The result of this step was a list of values. The second was placing the event list into the

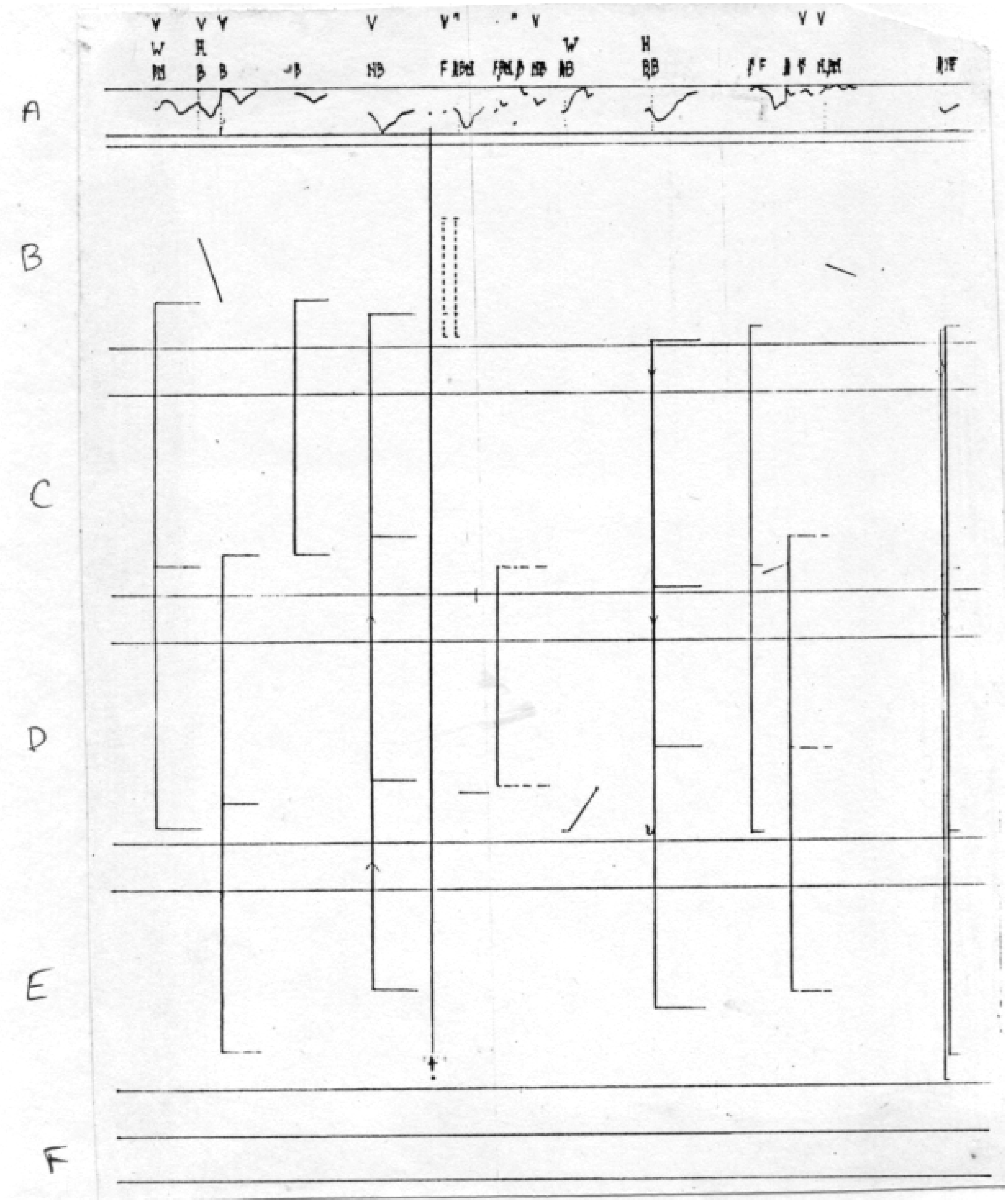


Figure 2.1: *59 $\frac{1}{2}$" for a String Player*, excerpt.

score by determining and plotting the parameter values and determining and adding the bow technique markup.

It isn't necessary to explain in great detail the process Cage used to determine the event sequence and the parametric values. It should suffice to say that nearly every decision after the initial schematization of sound events was determined randomly using the *I Ching*.

What is striking about *59 $\frac{1}{2}$" for a String Player* and the rest of "The Ten Thousand Things" pieces, and also what is most significant in establishing context for my work, is the transformation of the idea of the score as a description of a musical ideal into instructions regarding the mechanics of sound production. Put another way, the score now drives the musician, rather than leads them.

What differentiates Cage's work here from mine is that Cage's notation is ametric and mine retains meter and traditional rhythmic notation. Also, his selection processes are random. He was determined to remove conscious intention from the composing process. In my work, I'm interested in creating rhythmically coordinated ensemble textures, drawing on my experience as a performer who is knowledgeable with the extended techniques on many instruments.

2.2 Earl Brown's *Folio and Four Systems*

Composed around the same time as "The Ten Thousand Things", the pieces in Earle Brown's collection *Folio and Four Systems* (1952–54) engage with notational ambiguity. Each of the eight pieces deconstruct common practice music notation by stripping away its graphical objects and conventions that define it (and in a few of them, construct new encodings). This draws the performer into a different kind of relationship with the score and calls into question issues of interpretation and reproducibility. A survey of a number of recordings of *Four Systems* reveals wildly different sounding performance with a range of instrumentation, duration and texture. Each could be considered a faithful and thoughtful interpretation of the score.

Of the eight pieces, the scores for *October 1952*, *MM – 87*, and *MM – 135 March 1953* most closely resemble common practice music notation. They contain all the elements of common practice notation except two: bar lines and time signatures. *October 1952* dispenses with metronome markings. In all three, despite precisely notating durations using beams, flags, stems, dots, tuplets, ties, and filled/unfilled noteheads, Brown leaves indeterminate any sense of proportional relation among the events of the piece. The order and superimposition of durations is metrically incoherent. Brown does not use rests, which means silences are implied rather than explicit. The prefatory note gives the performer permission to "move through the space at a constant or variable rate of speed relative to 'real' time or to intuitive time."

In *Music for "Trio for Five Dancers"*, Brown transcribed and translated the spatial positions of the dancers to notes' positions on a staff. Here again, bar lines, time signatures, metronome markings are absent. Additionally, Brown reduces duration indicators to a binary where an open note head is long, to be held until the the sound dies away, and a closed note head is shorter. The score contains no dynamics or articulations.

Figure 2.2: *October 1952*, excerpt.

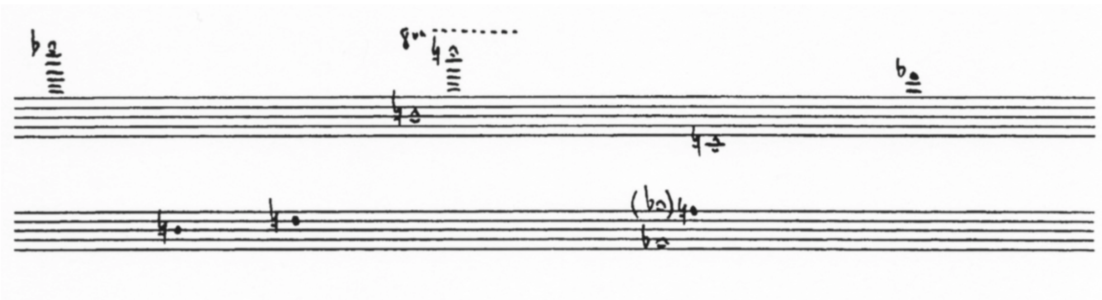


Figure 2.3: *Music for "Trio for Five Dancers"*, excerpt.

The notation for *1953* was designed with some symbols (accidentals, dynamic markings) modified to be horizontally symmetrical so that the page could be turned upside down, and still be readable. In a move towards a more spatial than symbolic representation of time, noteheads are replaced with thick lines whose lengths represent duration. According the prefatory note, their lengths and positions are to be consistent relative to each other and the width of the staff.

Perplexingly, *November 1952* dispenses with the basic requirement of common practice notation that the horizontal axis of the staff represents the flow of time from

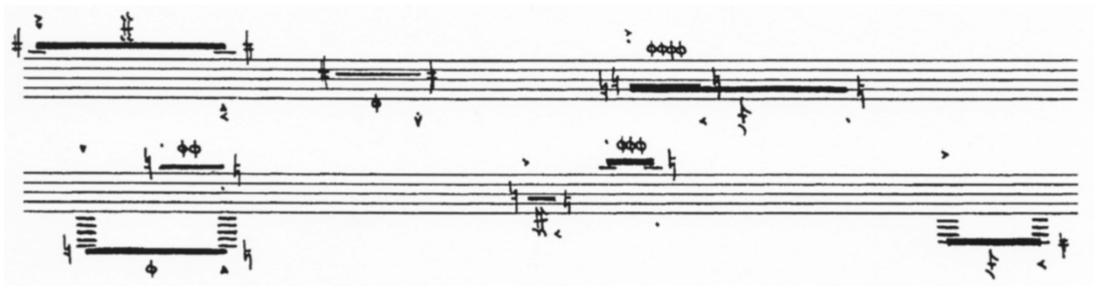


Figure 2.4: *1953*, excerpt.

left to right [1]. The horizontal position of the notes on the staff serve only to visually differentiate them from one another. They are temporally unordered and durations are not specified. Brown greatly expands the number of lines in the staff, suggesting an infinite pitch space. Without a clef, there is no reference for pitch height, and the performer is left to determine pitches for themselves. The prefatory note suggests the performer's eye movements provide a local context for pitch height. Their field of vision provides a referential frame. As the performer scans through the staff, pitch relationships change.

Four Systems looks like a piano roll, but the horizontal lines have varying thickness. The instructions at the bottom of the page are simple and short enough to quote: "May be played in any sequence, either side up, at any tempo(i). The continuous lines from far left to far right define the outer limits of the keyboard. Thickness may indicate dynamics or clusters." By removing staff lines and presenting only the extremities of the piano (or other instrument(s)), Brown turns a formerly discrete parameter

[1] As Brown says in the prefatory note: "Line and spaces may be thought of as tracks moving in either direction..."

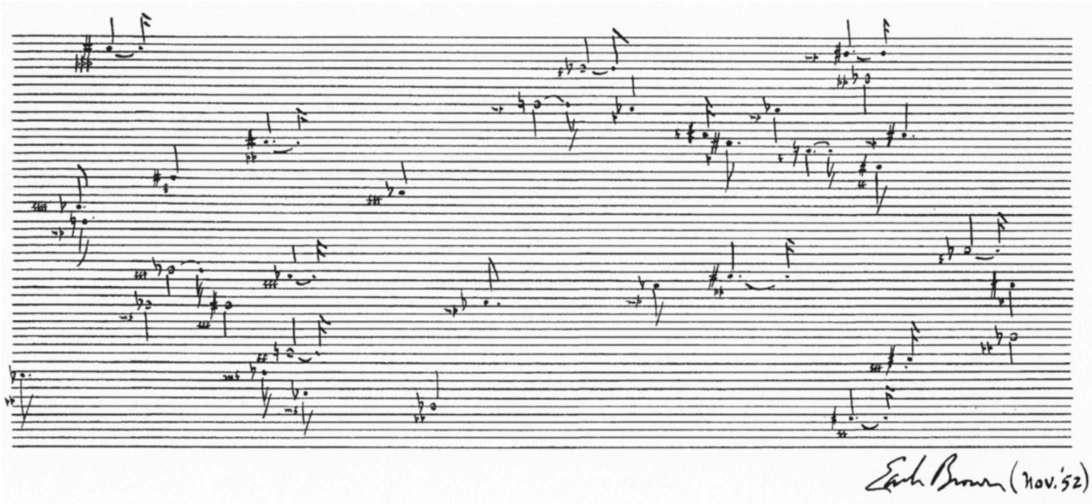


Figure 2.5: *November 1952*.

space into a (conceptually) continuous one. It becomes difficult to measure precisely the pitch interval between two events. Determining pitch relationships becomes more of a process of estimation.

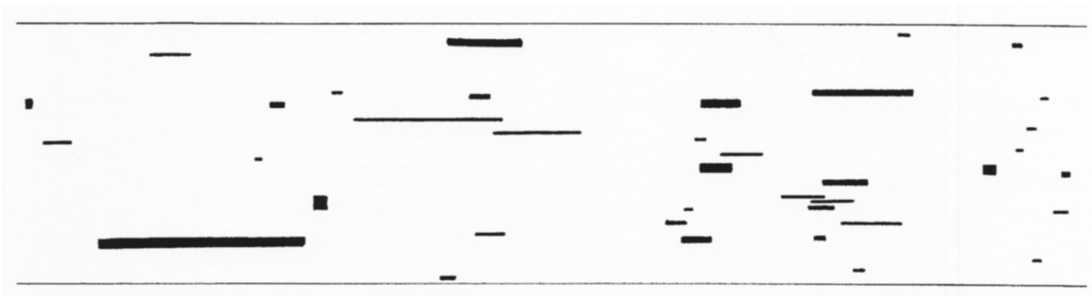


Figure 2.6: *Four Systems*, excerpt.

Lastly, *December 1952* dispenses with every convention of common practice music notation. It consists of rectangles of various proportions distributed randomly on the page. The space is not bounded by any kind of borders except the edge of the page.

The page can be oriented with any of the four edges facing up. The orthogonality of the shapes suggests two axes at a right angle, yet the performer isn't given a hint on how they should be encoded. It is clear that rectangles are to be interpreted as some sort of sound event, but how the performer is to interpret and sequence them is left entirely open.

There are no direct implementations of Brown's notational innovation in *Heave, Sway, Surge*. However, traces of Brown's application of spatial representation of a parameter versus time, especially in *Four Systems*, are evident in the parametric envelope and tablature staves of *Heave, Sway, Surge*.

2.3 György Ligeti's *Chamber Concerto*

Dense musical texture is a central preoccupation of *Heave, Sway, Surge*. I use it to try to evoke, at least in abstract way, the physicality of matter undergoing change and feelings of motion. Creating a sound-mass requires the accretion of many layers of sound such that no part is distinguishable from the whole.

In his *Chamber Concerto* (1970), György Ligeti created sound-mass textures of an opacity usually achieved with a larger orchestra, using only 13 instruments. Ligeti creates opaque textures through a technique which he called micropolyphony. Ligeti describes it as a kind of canon:

> ...you cannot actually hear the polyphony, the canon. You hear a kind of impenetrable texture, something like a very densely woven cobweb. I have retained melodic lines in the process of composition, they are governed by rules as strict as Palestrina's or those of the Flemish school, but the rules of this polyphony are worked out by me. The polyphonic structure does

Figure 2.7: *December 1952*

> not come through, you cannot hear it; it remains hidden in a microscopic, underwater world, to us inaudible. [Bernard, 1994]

Not every moment in the score qualifies as this type of texture. Density varies. Sustained clusters predominate some sections. Melodic figuration and drones can also be found. However, micropolyphonic textures are dominant throughout.

The developmental aspect of the piece involves textural evolution through gradual changes in various musical dimensions, as well as sharp contrasts between successive textures, plus textural superimposition. It has a more narrative-like flow than other process-oriented music of the era that might rely on small sets of pitches which are repeated and reordered, like Steve Reich's *Piano Phase* (1967).

The first movement provides a prime example of micropolyphony. The movement can be divided into two main sections, with a short interlude between the two. Each section is defined by a sound mass texture. The first, which spans the beginning of the movement to rehearsal letter M (about two thirds into the movement), consists of of a narrow pitch cluster. Each instrument in the ensemble, at various points, is given a pseudo-random trill that animates a chromatic cluster between four and seven semitones. The entire ensemble is constrained to a very small pitch range. This helps the sounds of the instruments fuse into a composite.

The texture of the second section has a much wider pitch range, spanning almost the gamut of pitches available to the instruments of the ensemble. Here the individual instruments are more discernible, but Ligeti deploys the entire ensemble with very dense rhythm and wide melodic intervals to reduce the perceptibility of linear motion in any one instrument.

Pertaining to the micropolyphonic textures, there are two approaches to rhythm evident in the score. One approach is a precisely notated ensemble polyrhythm. The movement is written in $\frac{4}{4}$ time at 60 beats per minute, with a few exceptional moments. To have available a number of pulse rates, and to maximize rhythmic independence, Ligeti divides the quarter note into three to nine pulses.

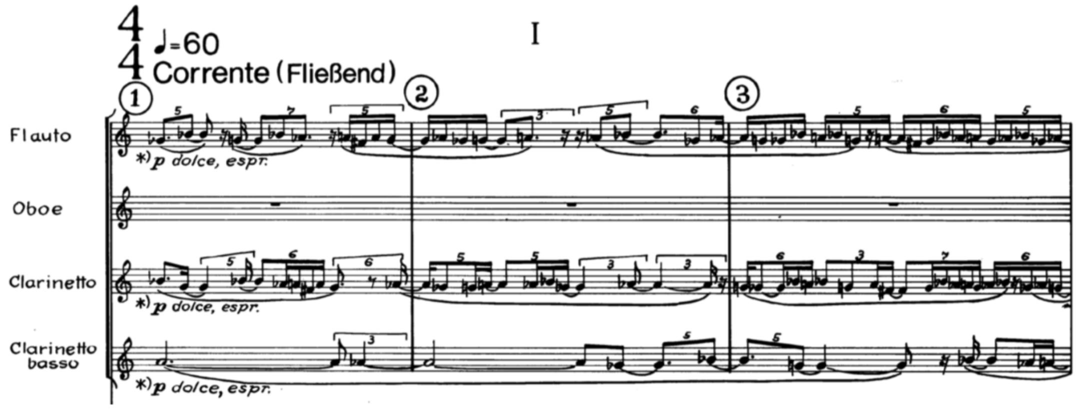


Figure 2.8: *Chamber Concerto*, excerpt (mm. 1–4, woodwinds)

Each part moves through this set of pulse rates, changing on each beat. Successive notes are tied to reduce density in places. Notes on measure downbeats are often tied from the previous bar. The overall effect is a diminished sense of pulse and meter, but with a tightly controlled flow of temporal density. The other approach is an unmeasured trill with indications to play as fast as possible, and are often found in measures with a long fermata, but are sometimes paired alongside measured rhythms.

The score is information-dense and appears complex, but an analysis of the first section reveals a fairly straightforward formal procedure. The cluster at the beginning consists of the chromatic range between pitch numbers 66 and 70 (where middle C = 60). It gradually expands and shifts upwards to its widest point [67,...,74] after rehearsal letter I. After that it shrinks to the dyad [72, 73] at rehearsal letter L. The number of measures between each rehearsal letter is no more than 5. Each rehearsal number generally marks a change in active instrumentation. Starting at rehearsal letter E, each subsection defined by the letters alternates between (1) one or two measures with a fermata containing an unmeasured trill with an indication for approximate number of seconds to hold the fermata, and (2) a few measures of precisely notated rhythmic activity. In terms of temporal density, there is a trend over the course of the section from relative low to high density.

I use a similar approach to layering trill-like figures multiple pulse rates in *Heave, Sway, Surge.* Figure 2.9 shows a micropolyphonic texture in action. This texture goes even further and adds polyrhythmic activity between the components within an individual instrument. Whereas Ligeti created pulse rates by dividing the quarter note into three to nine pulses, I subdivide at the measure level. Time signatures are in constant flux, which a greater variety of pulse rates.

2.4 Helmut Lachenmann's *Pression*

The focus of innovation in much of Helmut Lachenmann's music is concerned with the mechanical aspects of instrumental sound production. *Pression* (1969), for

Rehearsal Letter	Cluster Pitches	Cluster Pitch Range	No. of Instruments
measure 1	66–70	4	8
A	66–70	4	11
B	66-70	3	10
C	66–72	5	5
D	67, 69–72	5	10
E	67, 69–72	5	4
F	67, 69–72	7	7
G	67, 68, 70, 72, 74	7	8
H	67, 68, 70, 72, 74	7	13
I	67-74	7	4
J	68-74	6	10
K	69-74	5	10
L	73, 74	2	4

Table 2.1: *Chamber Concerto*, cluster analysis: rehearsal letters A–L.

cello, represents an intensification of this interest. Ian Pace points out that in this work, "the cellist is called upon to play the instrument in almost every conceivable manner except the standard one; the bow is applied both below and on the bridge, on the frog, and to parts of the shell, the fingers of the left hand are rubbed against the strings, the strings are overbowed, and so on." [Pace, 2008, 12]. Through a notation that indicates actions instead resulting sounds, Lachenmann creates a work whose reality exists as much in performance – with a visual aspect – as it does in the score, and whose form can be at least partially understood in terms of how the player's hands are applied to different parts of the instrument.

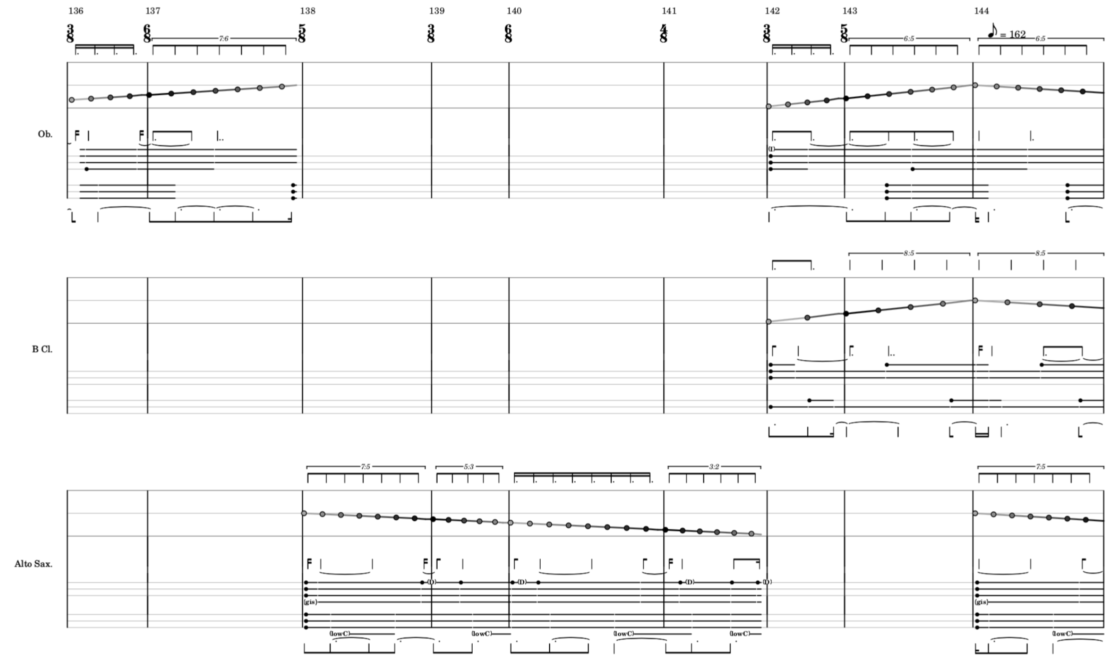


Figure 2.9: *Heave, Sway, Surge*, excerpt (segment I, mm. 136–144, woodwinds).

Pression's score only vaguely resembles traditional music notation. There is a semblance of a staff, with a horizontal dimension representing time, and a vertical dimension representing the performance space of the cello. Although there are regularly spaced marks atop the staff demarcating a quarter note duration (corresponding to a tempo marking of 66 beats per minute), there are no time signatures or barlines. Various notehead shapes indicate the location of actions and their timing. Their duration is indicated by a horizontal line extending to the right of the notehead.

Instead of a traditional clef, we find a graphic depiction of the cello viewed from the perspective of the cellist, with the tailpiece at the top, and the fingerboard at the bottom. Lachenmann uses it describe the precise location of actions to be performed and the kinds of direction and speed of motions involved.

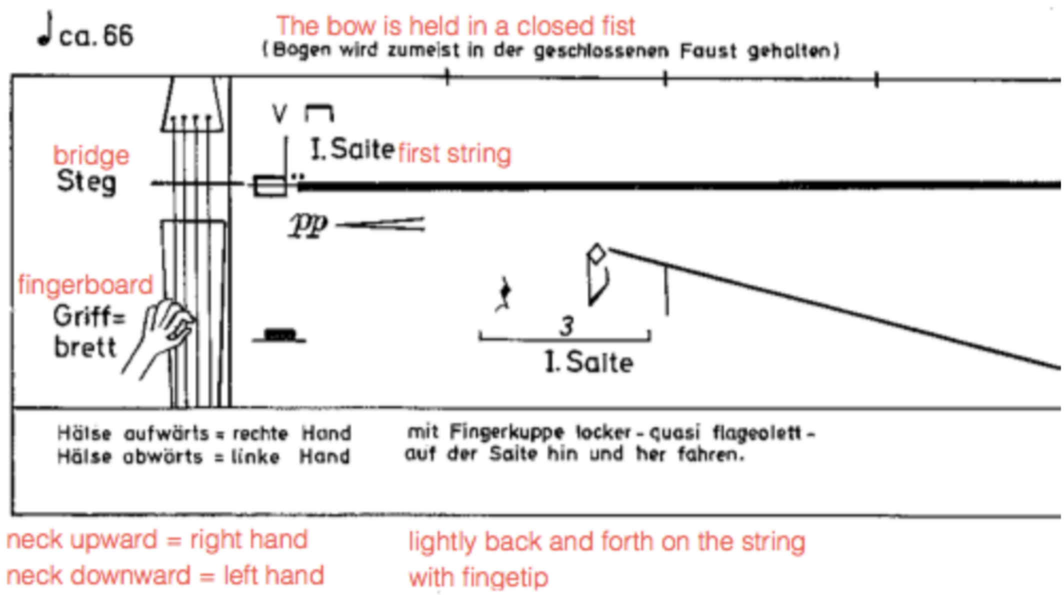


Figure 2.10: *Pression*, excerpt (first system).

Figure 2.10 shows the first few beats of the piece. The English text is my translation of Lachenmann's annotations. The score may be interpreted verbally as follows:

> First, holding the bow in a closed fist, draw the bow over the top of the bridge over the first string with very light but increasing pressure, freely alternating the direction of the bow as necessary. Concurrently, lightly drag the fingertip along the length of the string, starting near the lower end of the fingerboard and moving toward the nut.

Though the piece can't be reduced to clear sections, I've identified 11 divisions defined by a concentration on one or two methods of sound production, supported by my perception of the similarity and difference of timbres in a recording. It helps to show that Lachenmann's approach to form in *Pression* is largely progressive, i.e. that for the most part, each section is different from all previous sections. Exceptions are the first and eleventh sections and the eighth and tenth sections.

Number	Label	Method of Sound Production
1	A	Bowing on bridge, rubbing strings w/ L.H.
2	B	Rubbing fingers on bow-stick
3	C	Dragging bow vertically/diagonally on strings
4	D	Bowing on the string windings, plucking, strings behind bridge
5	E	Rubbing strings w/ L.H., bowing strings behind bridge
6	F	Bouncing bow-stick/hair on strings, bridge body
7	G	Rubbing strings w/ L.H., bowing on tail piece
8	H	Bowing on bridge, rubbing strings w/ L.H., bowing on string with string dampened with L.H.
9	I	Bowing on two strings, unison with open string, microtonal gradation
10	H	Bowing on string with string dampened with L.H.
11	A	Rubbing strings w/ L.H., bouncing bow stick on strings

Table 2.2: *Pression*, form analysis.

Figure 2.11 shows the first section of *Pression* in its entirety. By treating the left and right hands as separate sound- producing entities, Lachenmann is able to create a polyphonic structure. The first sound we hear, created by bowing on the bridge, might be categorized as a "sound-color," using Lachenmann's 1966 typology [2]. Although the

[2]In his 1966 article, "Klangtypen der Neuen Musik" ("Timbral Categories in Contemporary Music"), Lachenmann created a typology of five "sound structures" differentiated by their perceptual complexity. The first and simplest category is "sound-cadence," which describes the loudness envelope of a single sound. The second, "sound-color," describes a sound with a stable, unchanging timbre. The third category, "fluctuation-sound," denotes a type of sound that contains regular internal differentiation. This might manifest in a trill or tremolo, or even an ostinato. "Texture-sound," the fourth type, describes a complex sound whose internal differentiation shows no obvious patterns of repetition or periodicity, and whose components are difficult to perceptually disentangle. Lachenmann describes the fifth category, "structure-sound," as a "polyphony of ordered juxtapositions" of the other structural categories that "opens out gradually through a multi-layered, multi-significant process." [Lachenmann, 1970]

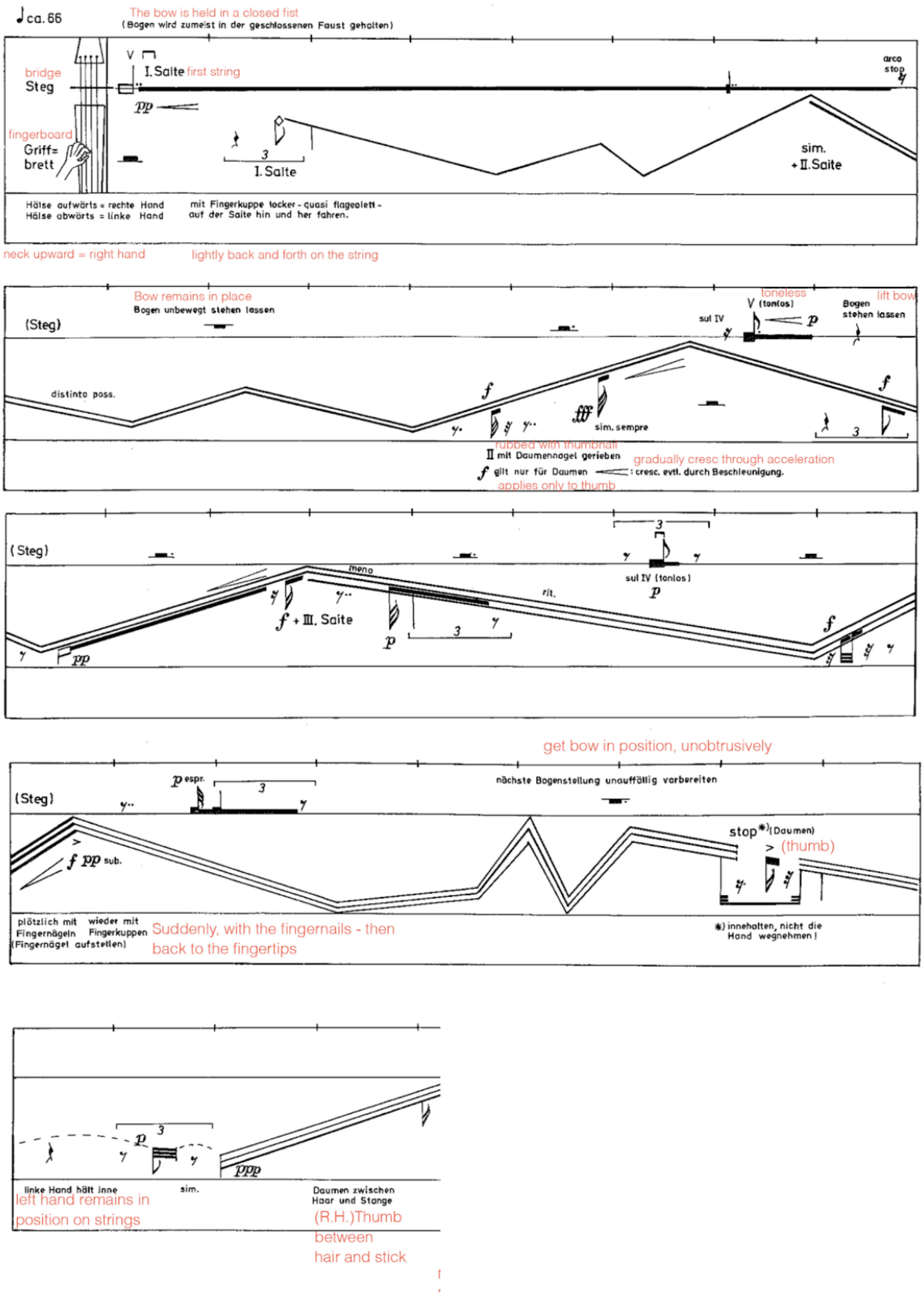


Figure 2.11: *Pression*, excerpt (first section).

bow touches the string during this action, it doesn't actually set the string in motion, and what we hear is a broadband noise spectrum created by the friction of bow-hairs passing over the wood of the bridge. Apart from the small increase in pressure at the beginning, the sound is relatively continuous, with little change in spectrum over time.

The sound created by the left hand gliding over the strings has a definite pitch, resulting from the minute periodic impacts between the cellist's fingertip and the regularly spaced edges of the string winding. The frequency of this pitch is determined by the speed of the hand moving along the string. It can be read in the score by observing the slope of the line indicating the left hand's position. The steeper the slope of the line, the higher the resulting pitch.

A third action, a variant of the second, involves scraping a string with the left-hand thumbnail. This sound is louder, because of the hardness of the thumbnail; and higher due to the rapidity of its movement: juxtaposed with quieter sounds it functions as kind of an accent. Over the backdrop of the left-hand motion, the structure of this section becomes a play of alternation between the thumbnail scrape and the bridge-bowing.

Figure 2.12 shows the complete sixth section, where another quasi-polyphony is produced by bouncing the bow-stick on the strings and the bow hair on the body and the bridge. In each action, increased pressure with the right hand reduces the height of each successive rebound, which increases the speed of the bounce until the bow comes to rest. Striking the bow-stick against the strings produces a short pitched sound whose frequency depends on the closeness of the bow to the bridge. A gradation of timbral

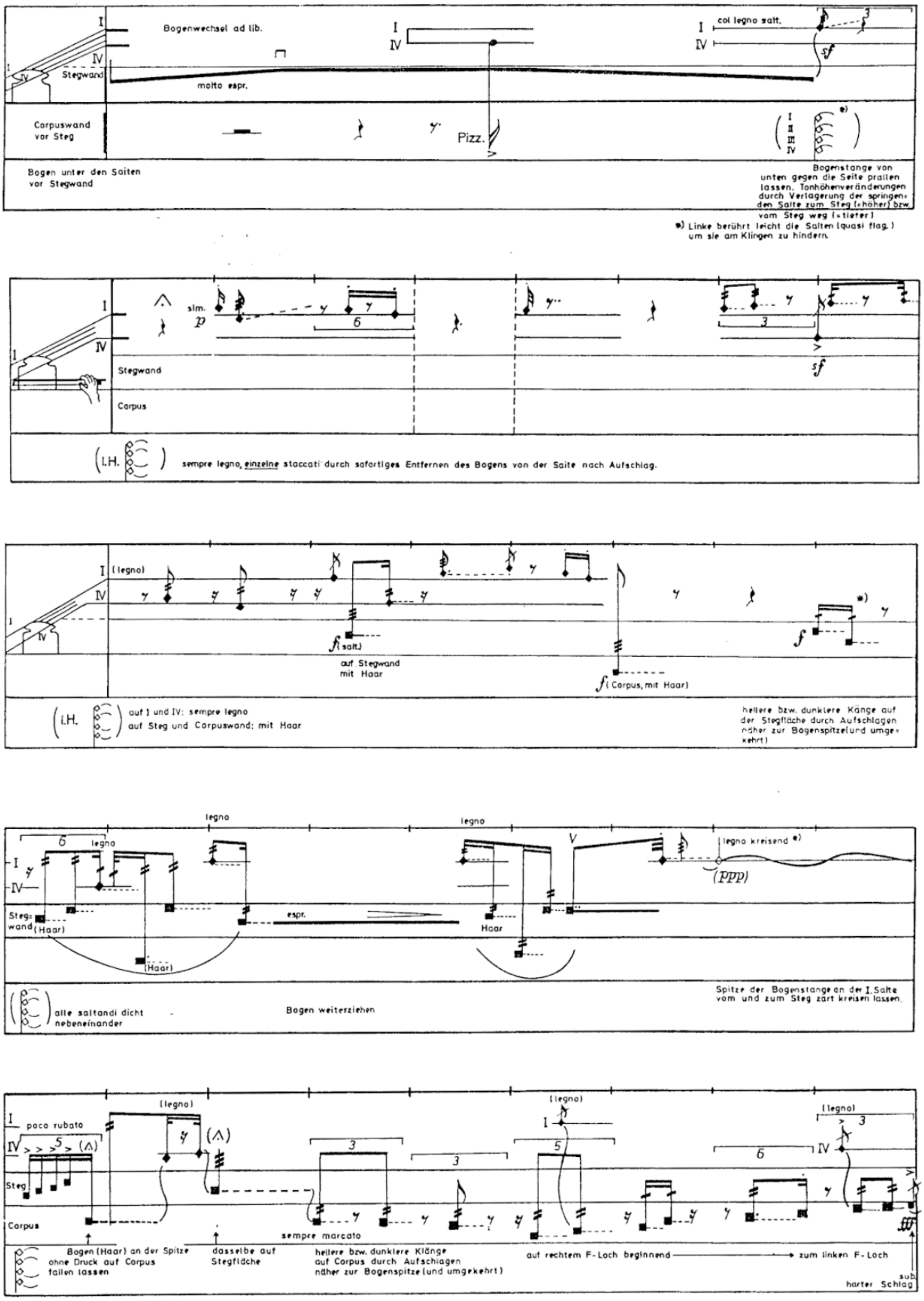


Figure 2.12: *Pression*, excerpt (section six).

brightness is achieved in the hair-on-bridge and hair-on-body actions by changing the location of the contact point.

The section begins with a concentration on the first string, and then incorporates the fourth. After making a few gestures on the body and bridge, there is a rapid movement between all three of these actions in the fourth line of the example, made possible by having the cellist hold bow stick between the strings and the body.

Even though they share some similarities regarding instrumental decomposition, Lachenmann's approach differs from that of Cage (and of mine). Lachenmann is less interested in schematizing and quantifying the forces involved in sound production, and more interested in expanding the sounding surfaces of the instrument and defining techniques to activate them. In this way, Lachenmann doesn't so much break apart the cello into its constituent mechanical parts, but redefines the function of each component (bridge, tailpiece, soundboard, bow stick) as independent sound producing mechanisms.

2.5 Conclusion

The works mentioned above are culturally significant for a number of reasons. They are are results, in part, of novel methods of composition. They also contributed to new understandings of structure. Lastly, they stimulated new thought about music perception.

These works are important for me as an artist, my composition work in general and the composing of *Heave, Sway, Surge* in particular. They significantly predate my work. The pieces by Cage and Brown mentioned above were composed about 70 years prior to *Heave, Sway, Surge*, which was completed a month before the time of this writing.

The compositions and writings of Cage, Brown, Lachenmann, and Ligeti have continually sparked my imagination throughout my development as a composer. They also inform my work directly or indirectly through a network of influence on subsequent composers and pieces. Cage schematizes instrumental technique in order to sequence and recombine in fresh and novel ways. Brown questions the assumptions of musical notation and expands on its ability to communicate instructions to a performer. Lachenmann examines fundamentals of sound production. Ligeti weaves rich micropolyhonic textures with a minimum of means. These elements are all at play in *Heave, Sway, Surge*.

Chapter 3

Modeling

Composing with physical actions entails creating events. An event is associated with a set of parameters that are either discrete or change continuously over the event's lifetime. In a way, a musician playing *Heave, Sway, Surge* is like a sophisticated and autonomous function that interprets a set of parameters to produce a sound event. In order to determine these parameters I needed to model instrumental techniques and their acoustics.

Instrument modeling has been done in different ways, to various ends. Physical modeling synthesis attempts to mimic the sounds of acoustic instruments by simulating the physics of vibration using mathematical equations. For example, the Karplus-Strong algorithm models the physics of a vibrating string to produce a lifelike simulation of a string-instrument in a computationally inexpensive manner [Karplus and Strong, 1983]. Composers like John Cage [Pritchett, 2009], Helmut Lachenmann [Pace, 2008], Klaus K. Hübler [Hübler, 1984] and Aaron Cassidy [Cassidy, 2013] relied on thoughtful considerations of the function of individual components in the mechanical system that comprises an instrument and a performer to produce compositions that redefine musical materials and expand the sonic boundaries of instrumental performance.

To prepare for *Heave, Sway, Surge*, I devised a framework to think about the combination and interaction of physical forces and their aural results. It allowed the definition of performance parameters that can be represented in code as data structures and in the score as graphical objects. After some research into the acoustics of musical instruments and after examining approaches by other composers, I defined a model that formed the basis for my composition.

To design the model, I broke down the performance techniques of each instrument of my chosen ensemble into their primary mechanisms. If I could generalize these component actions, I could classify each instrument into a small number of categories. This would ease the burden of defining models for each instrument.

It is important to note that the derived parameter spaces aren't formed from precisely measured physical quantities. The navigation of these parameter spaces by a musician is shaped by historical practices and personal aesthetics. They are abstractions that depend on established playing techniques that align with the design of an instrument, however much the prescribed navigations undermine those techniques. Although they allow for a range of sonic possibilities, they are centered around the forces necessary to produce a stable tone.

Inspired by concepts from physical modeling synthesis, I employed a two-part model of the sound-producing interactions between musician and instrument. The first component, called an excitator, generates the mechanical energy required to create a standing wave inside the resonant body of the instrument. Playing a reed instrument involves the lungs, lips and a mouthpiece with one or two reeds. In the violin family it involves the arm, a rosined bow and a stretched string.

The second part is a mechanism called a resonance modulator, which alters the resonant characteristics of the objects that determine the standing wave. On a bowed string instrument it involves the left hand fingers, the fingerboard and the bowed string. In the reeds, the modifying component consists of the fingers, keys and the tube that forms the body of the instrument. Both components have variable properties whose manipulations, when combined, form a field of potential acoustic states.

The instrumentation of *Heave, Sway, Surge* consists of oboe, clarinet, saxophone, two nylon string guitars, violin, viola, cello and double bass. Conceiving each instrument as a pair of components – a generating component and a modifying component – allowed me to group them into four three categories: woodwinds, guitar and bowed strings. Each category has a distinct set of parameters. As such, each requires a distinct notational strategy.

These categories align with standard categories found in music literature. However, it is worth noting that for the purposes of this composition, its notation and its software, each category sets aside certain techniques common to the instruments in each category and which are unique to the categories themselves.

Class	Excitator	Resonance modulator	Exc. Parameters	Res. Mod. Parameters
Woodwinds	Lungs, embouchure	Fingers, keys	Air and lip pressure	Key config.
Bowed Strings	Bow, string	String, fingerboard	Pressure, position, str. index	Pressure, position, str. index
Guitar	Finger, string	Finger, string, fret	Force, position	Pressure, fret index, str. index

Table 3.1: Instrument categories and primary parameters according to excitator/resonance modulator schema.

3.1 Woodwinds

The woodwinds category includes the oboe, clarinet and saxophone. It is defined by a reed-based excitator and key-based resonance modulator. The excitator creates energy through a combination of lung-powered air-flow and embouchure. In the embouchure, pressure from the lips closes the gap between the reed and the mouthpiece (or the gap between two parallel reeds, in the case of the oboe). If the distance between the reed and its opposite is appropriately small, this gap will open and close in a periodic manner. The puffs of air that pass this boundary sets in motion the air column inside the tube.

The periodic motion of air molecules in the resonance modulator forms a standing wave. The variation in air pressure compresses and rarefies the air molecules. Pressure differentials at each end of the tube create an alternating cycle of compression and rarefaction waves whose frequency is determined by the length of the tube. This standing wave manifests as an acoustic sound, perceived as a tone with a stable pitch.

Fractional nodes add upper partials whose frequencies are harmonically related. A number of precisely spaced holes drilled into the side of the tube can be covered and uncovered with a keying mechanism or directly with the fingers. This changes the effective length of the tube, changing the resulting pitch.

I chose air pressure, lip pressure and left- and right-hand fingerings to be the primary parameters. The parameter space for air pressure is continuous. Its range is defined as the minimum amount of exhaling force by the lungs necessary to move air into the body of the instrument, to the maximum possible exhaling force. It is encoded as a real number between zero and one, inclusive. With other parameters remaining constant, changes in air pressure translate to proportional changes in volume. Additionally, there is a certain amount of broadband noise created by breath escaping the instrument. The loudness of the sound is largely invariant with respect to air pressure, and is fairly quiet. In a sense, modulating air pressure changes the balance between the tone produced in the resonating chamber and the breath noise. Playing at low volumes produces what musicians call a "breathy" sound.

Lip pressure is also a continuous parameter. At low levels, the distance between reed and the mouthpiece is too great for the air current to induce the periodic movement that creates a standing wave in the resonating chamber. Broadband noise is emitted as the air current under constant pressure passes along the inner surfaces of the instrument. Below that threshold, variations in lip pressure are insignificant. However, above that threshold, a variety of chirps and squeaks are possible as the reed itself vibrates. The results are both difficult to control and difficult to predict. The parameter space for lip pressure is defined as the range between zero pressure to the amount of pressure necessary so that the reed is flush with the mouthpiece and cannot vibrate. Lip pressure is encoded as a real number between zero and one, inclusive.

A fingering is a set of mappings from a finger index to a list containing a key label and its state, which is either depressed or not depressed. The parameter space of key configurations is therefore a discrete one, containing all the combinations of each possible mapping in their on and off states. The resonant frequency of the instrument body changes proportionately with its effective length (i.e., the length of the standing wave inside the body). The tone holes which the fingering mechanisms open and close change the effective length. By opening some of the higher tone holes while keeping the lower ones closed, it is possible to create two or more standing waves, with the sounding result of a tone with two or more distinct pitches. The mechanical action of the key work is also audible.

Table 3.2 enumerates the parameters used in the composition, notation and software for the woodwind category. The importance column prioritizes a parameter to determine how the parameter will be encoded in the notation. This will be discussed in more detail in the next chapter. The column labeled "Discrete/Continuous" indicates whether or not the value changes over the duration of an event. The ability for a parameter to be represented as discrete or continuous is constrained by the capabilities of the notation system. Trills and vibrato can of course be modulated in performance, but the notation I use for *Heave, Sway, Surge* is only capable of rendering a single, primary parameter per staff as continuously changing over an event timespan.

Name	Importance	Discrete or Continuous	Component	Datatype
Air pressure	Primary	Continuous	Excitator	Float
Lip pressure	Primary	Discrete	Excitator	Float
Vibrato	Secondary	Discrete	Excitator	Boolean
Staccato	Secondary	Discrete	Excitator	Boolean
Fingering (LH)	Primary	Discrete	Resonance modulator	Map
Fingering (RH)	Primary	Discrete	Resonance modulator	Map
Trill	Secondary	Discrete	Resonance modulator	Boolean

Table 3.2: Woodwind parameters

3.2 Guitar

The excitator of a guitar involves the right hand fingers and the strings. The resonance modulator consists of the left hand fingers, the frets, and the strings. In the excitator component, the finger plucks a string: the impulse created by increasing the tension of the string and suddenly releasing it generates a standing wave in the string. The frequency of the standing wave is dependent on the length of the string as well as its mass and tension. The energy of the vibrating string is transduced into fluctuations in air pressure by the bridge, which acoustically couples the sound box, which amplifies the sound waves.

The primary parameters involved in the excitator are plucking force and plucking position. Plucking force is the energy required to displace the string and increase its tension before its release. Greater plucking force affects the amplitude of the string vibration, translating to greater volume. It is encoded as a real number between zero and one. Zero represents the minimum force necessary to set the string in motion. One represents a reasonable maximum of force (one that wouldn't cause damage to the string, instrument body or injury to the musician's fingers). Plucking position is defined as the location on the string in between the bridge and the edge of the fingerboard. It also encoded as a real number between zero and one, where zero equals the location where the string meets the bridge. Plucking nearer to the bridge strengthens the amplitude of the upper partials relative to the fundamental, resulting in a brighter sound.

In the resonance modulator component, the fingers depress the string against the fingerboard behind a particular fret. This changes the string's effective length and therefore the frequency of its vibration. With a finger at one of the harmonic nodes of the string, with light enough pressure that the string doesn't make contact with the fret, the string's vibration will be forced into a harmonic mode, isolating an upper partial (a natural harmonic). The guitar model parametrizes fretting as a set of mappings, where a finger index is mapped to a tuple. The first element of the tuple is itself a tuple containing a fret index and a string index (both integers). The second element is a Boolean value that represents whether finger pressure is light enough to produce a harmonic.

Name	Importance	Discrete or Continuous	Component	Data Type
Plucking position	Primary	Continuous	Excitator	Float
Plucking force	Primary	Discrete	Excitator	Float
Tremolo	Secondary	Discrete	Excitator	Boolean
Fretting	Primary	Discrete	Resonance modulator	Map

Table 3.3: Guitar parameters

3.3 Bowed Strings

The instruments of the bowed-string category are topologically identical. Each functions in the same manner. What differentiates them is their size, the magnitude of the forces involved, and the instrument's orientation relative to the player. The excitator in this category involves the right arm, hand and fingers, the bow and the strings. The resonance modulator involves the left hand fingers, the strings, the fingerboard, the bridge and sound box.

In the excitator component, a rosined bow is drawn across the string. According to a slip-stick phenomenon, the two surfaces alternate between sticking to each other and sliding against each other. This cycle of friction causes vibration in the string. It eventually forms a standing wave. The parameters I determined to have the greatest effect on the sound are bow position, bow pressure and bow speed. I eliminated bow speed and direction from the model for reasons pertaining to notational and performance complexity. In the score, these decisions are left to the musician.

Bowing position is defined as the contact point of the bow relative to the axis of the string. It is encoded as a real number where zero equals the point at which the string meets the nut and one equals the point on where the string meets the bridge. Like with plucking position on the guitar, changing bow height affects the balance between the fundamental and upper partials.

Bow pressure is the downward force applied to the string. Pressure regulates friction. Its variance affects the volume of the resulting sound, but also other more subtle properties. Applying more pressure than necessary to produce a sound can create grinding and crunching noises. A secondary acoustic situation occurs as the hairs of the bow vibrate, producing a soft broadband noise. Bowing very lightly changes the balance of this sound and the sound of the vibrating string, producing a breathy effect. Bow pressure is encoded as a real number between zero and one, where zero means enough pressure to keep the bow on the string, but not enough to produce a tone; and one means more pressure than necessary, so that the tone becomes unstable (some call this technique "overpressure").

Echoing the mechanics of the guitar described earlier, the vibration of the string is modified in two ways in the resonance modulator component. By pressing the string against the fingerboard with the finger, the effective string length is shortened, affecting the fundamental frequency of vibration. By touching but not stopping the string at certain locations on the string, the vibration is forced into a harmonic mode. Unlike the guitar, there are no frets, and finger location is thus a continuous space. The range from zero to one represents the location on the string between the nut and the bridge.

The bowed string model is more holistic than that of the guitar. Bow and finger locations are thought of as belonging to the same space (and are represented on a single staff in the notation). Therefore another parameter is introduced: the string index. This tells the performer which string to manipulate with bow and fingers. It is encoded as an integer.

Name	Importance	Discrete or Continuous	Component	Data Type
Bow position	Primary	Continuous	Excitator	Float
Bow pressure	Primary	Discrete	Excitator	Float
Bow tremolo	Secondary	Discrete	Excitator	Boolean
Staccato	Secondary	Discrete	Excitator	Boolean
Finger position	Primary	Continuous	Resonance modulator	Float
Finger pressure	Primary	Discrete	Resonance modulator	Float
String index	Primary	Discrete	Both	Integer [0, 3]

Table 3.4: Bowed-string parameters

Chapter 4

Notation

Common practice music notation evolved over centuries as a way to communicate musical data, with pitch and rhythm as central features. With *Heave, Sway, Surge*, I aimed to explore dimensions besides pitch as primary structural elements. With this goal in mind, I sought an alternative to the traditional five-line staff. I developed a notation strategy based on a specific set of requirements.

(1) The notation should be able to represent physical quantities such as air pressure, which change smoothly over time. (2) It must be able to represent discrete states of instrument mechanisms, such as a configuration of keys. (3) It has to coordinate the ensemble timing of complex passages in which the rate and type of change in any given instrument resembles that of complex twentieth century chamber music. (4) The score should be able to represent many parameters in a compact space, without excess visual clutter like descriptive text. (5) It must be intuitive to read and perform. In other words, it shouldn't require a great deal of time dedicated to deciphering its meaning and

intention. It should correspond naturally to the instrument. (6) The notation needs to balance interpretive freedom and specificity related to the forces involved in sound production.

My solution applies the model of instrumental performance I outlined in the previous chapter. Each of the three instrument classes (reed, guitar, bowed string) has a unique implementation. The solution is informed by graphical user interfaces in music production software, fretted instrument tablature, and the notational innovations of John Cage and Helmut Lachenmann described in chapter 2.

To understand the implementation of the solution, it is necessary to describe, briefly, the mechanics of LilyPond and how its rendered output can be customized. LilyPond scores are structured in hierarchical relationships of "contexts". A context is a kind of data structure that provides information to the rendering engine about what it should draw. There are contexts relating to the concept of a score, staff group, staff, and voice, to name a few of the most important ones. Lower level contexts like "Staff" and "Voice" are containers for note data. Contexts include a list of "engravers", which lets the rendering engine know what kind of graphical objects ("grobs") it can expect to render. The context structure of the score for *Heave, Sway, Surge* is visualized in figure 4.1.

In the remainder of this chapter, I discuss the three important contexts used in rendering the notation for *Heave, Sway, Surge* and the design and implementation of the parameter envelope staff, tablature staff, and rhythm staff.

- Score
  - Time signature staff
  - Woodwind staff group (one each for oboe, clarinet, saxophone)
    * Embouchure rhythm staff
    * Embouchure envelope staff
    * Left hand fingering rhythm staff
    * Left hand fingering tablature staff
    * Right hand fingering tablature staff
    * Right hand fingering rhythm staff
  - Guitar staff group (x2)
    * Plucking rhythm staff
    * Plucking envelope staff
    * Fretting tablature staff
    * Fretting rhythm staff
  - Bowed instrument staff group (one each for violin, viola, cello, bass)
    * Bowing rhythm staff
    * String space envelope staff (contains bowing and fingering envelopes)
    * Fingering rhythm staff

Figure 4.1: Score hierarchy.

4.1 Parameteric Envelopes

I often work with parameteric envelopes in Digital Audio Workstation (DAW) software applications. Envelopes are used to sequence control parameters for audio and MIDI tracks, effects and virtual instruments. They are sometimes called breakpoint functions. They are created by specifying control points (breakpoints) that represent a value at a point in time. The software interpolates between control points to produce smooth changes in a parameter.

Figure 4.3 shows an example of an envelope staff designed for this piece. Like

Figure 4.2: Track envelopes in Ableton Live.

a normal five-line staff, the horizontal axis represents time. The vertical dimension represents the range of the main parameter associated with staff. The changing values of the main parameter are encoded as a sequence of line segments. In this way the envelope staff is like a line chart often seen in the sciences, where the X axis is the independent variable and the Y axis is the dependent variable. A line segment in this context is analogous to a note. It marks an event, with a start, end and duration.

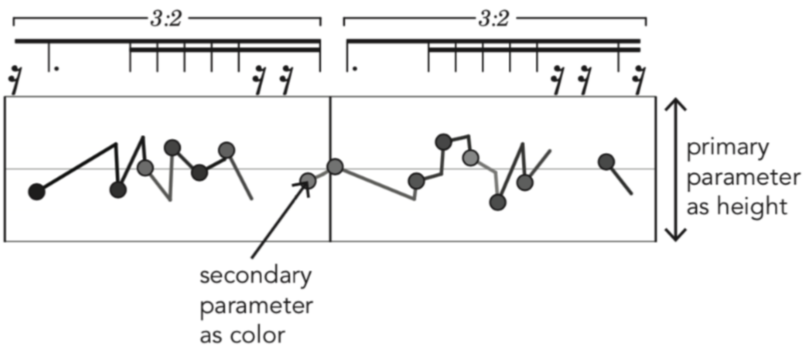


Figure 4.3: Parametric envelope staff.

For reed instruments, the envelope staff represents a continuum from low to high air pressure. The lines drawn on it represent changes in value. For guitar, the staff represents plucking position along a continuum from *tasto* to *ponticello*. And in the strings' envelope staff, there is one line for bow position and one line for finger position on the string.

Circles are drawn at the beginning of each line segment. This helps demarcate the line segments. It also provides an opportunity to encode a secondary parameter as the grayscale value of the filled portion of the circle. In the reeds this is lip pressure. In the guitars it is plucking force. In the strings it is bow and finger pressure. If a circle is drawn without a line segment, it is to be understood as a short, transient event, like a staccato.

Tertiary parameters are indicated in a few ways. Line style, i.e., whether the line is solid, dashed, or dotted, or wavy are associated with technique modifications like trills and tremolo. For the woodwinds, vowel formations and consonant articulations are rendered as text fragments.

Obviously the envelope staff satisfies the first of my requirements listed above: that it should express continuous parameters that change smoothly over time. It also satisfies four, five and six: it encodes up to four parameters in a small area through line position, circle color, line style, and bits of text. While it requires a legend to learn the various encodings, the similarity to a line chart should make it fairly accessible and intuitive.

The need to balance specificity and interpretive freedom raises questions about how a performer should translate an envelope to their instrument. The vertical space in an envelope staff is unruled, except to mark the location of the vertical center, and in the string staff, the edge of the fingerboard. The overall gestural feel of a sequence of line segments is prioritized over the value of a parameter at any specific moment. Contour and change is more important than accuracy or reproducibility. This gives the musician some latitude in how to map the visual values to the forces applied to their instrument.

The envelope staff is represented in LilyPond as a "Staff" context, with overrides at the context level and at the note level. At the level of context, I change the number of staff lines from the normal five. The reed and guitar staves have 15 staff lines. The bowed string instrument staff has 31. The top and bottom lines are colored dark gray. The center line is colored light gray and the rest are rendered invisible against the page by coloring them white. I hide accidentals, beams, clefs, duration-altering dots, flags, rests, stems, ties, time signatures, tuplet brackets and tuplet numbers. This leaves only staff lines, bar lines and and note heads, glissando lines and text markup visible (see Fig. 4.3).

Abjad provides an interface to one-time grob overrides for notes. I take advantage of this functionality to programmatically change grob properties based on parameter values. In the software package for *Heave, Sway, Surge*, which I will discuss in more detail later, a group of Python classes called "Handlers" transform common notation into custom staff types based on the instrument categories and according to a set of parameters. They take as arguments rhythmic information, parameter envelope data, and sequences of discrete parameter values.

4.2 Tablature

The tablature staff will be familiar to most guitarists. The woodwind tablature will be somewhat familiar to reed players, since it bears some resemblance to fingering diagrams encountered in pedagogical materials. This familiarity helps satisfy the requirement that the notation be intuitive.

Figure 4.4 shows an example of a woodwind tablature staff. Actually, it contains two tablature staves – one for each hand. In it, each horizontal line represents one of the main keys under the index, middle and ring fingers. The six lines of the guitar tablature staff represent the six strings of the guitar. Figure 4.5 shows an example of the guitar tablature staff.

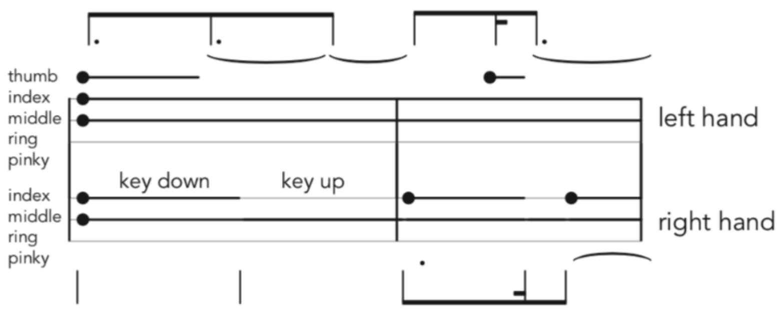


Figure 4.4: Woodwind fingering tablature staff.

Circles replace note heads on the woodwind staff. They show that a key is to be depressed. If a register key, trill key or other secondary key are required in a fingering, it is labeled with a pitch, small letter or descriptive abbreviation. In the guitar staff, numbers representing fret indices stand in for note heads. A diamond will be drawn

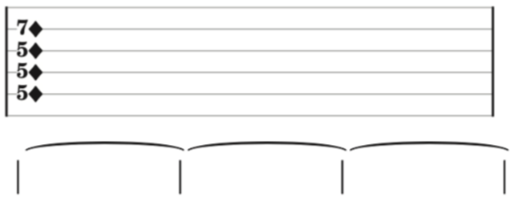


Figure 4.5: Guitar tablature staff.

next to the note head if harmonic pressure is required for that fingering. Horizontal lines extend to the right of the note heads, showing duration. For both the woodwind and guitar tablature, a dashed line indicates that a finger placement rapidly alternate between its depressed and non-depressed state.

The tablature staff satisfies the requirement that the notation is able to represent discrete configurations, since it can represent guitar and woodwind fingerings. It is able to do so in a compact manner, satisfying the requirement that it not take up too much space. The intuitiveness of this process arises from the reliance of tablature notation on well-established conventions. As far as interpretive freedom is concerned, the discrete nature of the parameter spaces involved do not allow much flexibility. For example, the state of a woodwind key is either fully depressed or it isn't.

Like the envelope staff, the LilyPond context for the tablature staff extends that of a normal five-line staff. Context-wide overrides include changing the number of staff lines and spacing them further apart. The number of staff lines is changed from five to three for reeds, and from five to six for guitar.

4.3 Time, Proportion and Rhythm

Neither staff type satisfies the important requirement that the score must communicate rhythmic data in a precise manner. Consequently, I chose to reintroduce common practice rhythmic notation. However, putting stems, beams, and dots inside the modified staff added undesirable clutter to the notation. Instead, I created a third type of staff containing rhythmic data that would be horizontally aligned with the significant parameter changes in another staff.

Starting from the concept of a single-line percussion staff, the rhythm staff context dispenses with everything but stems, dots, flags, beams, ties, rests and tuplets. Figure 4.6 shows an example.

Figure 4.6: Rhythm staff.

The decision to remove note heads was a difficult one. Noteheads serve two purposes. The first meaning they have is that they are a marker for pitch. Pitch is determined by a note head's vertical position on the staff and alteration through accidentals. But of course rhythmic information is also encoded in the difference between open and filled note heads in various contexts.

On the other hand, by removing note heads, the rhythm staff seems less like an independent staff, and more like an extension of the main parameter staff it is paired with. Put in close enough proximity, the stems appear to point directly to the noteheads in the main parameter staff.

The question remained how to signify durations that are usually signified by the notehead. The most appropriate solution was to represent durations greater than a quarter note using tied notes. This would guarantee that every note has a stem, and that every duration is representable without duration information derived from the notehead. One minor drawback is a preponderance of ties, but these are conventional enough that many musicians would likely regard the rhythms' stratification via conventional meters as an asset rather than a liability.

Chapter 5

Software

The software designed to compose and typeset *Heave, Sway, Surge* is in the form of a Python package. It's source code is hosted on Github. It relies heavily on the open source Python package Abjad (version 2.21), which provides an object-oriented model of music notation, and which renders special markup used by the LilyPond application to create vector graphics files (PDF or SVG). The `surge` package provides a framework that applies generative and transformational functions to structured musical materials to create an in-memory representation of a score.

The `surge` package consists of five subpackages. The `build` subpackage contains the entry point scripts that are used to initiate the build process for scores and parts. These scripts are run from the command line and take arguments pertaining to segment name, number of stages to build and for parts, the relevant instrument.

The `surge.includes` subpackage contains LilyPond stylesheets which provide the styling overrides that determine the look and feel of the score, specifying things like typefaces, line widths and automatic spacing settings.

The `surge.materials` subpackage contains the source material of the score, as a sort of database of musical material. It is organized hierarchically, first by segment, then by instrument and finally by instrumental mechanism.

The purpose of the `surge.segments` subpackage is to collect the materials appropriate to a particular segment and generate a score structure. The functions in this subpackage are called by the entry point scripts in `build` subpackage.

Finally, the `surge.tools` subpackage defines classes and functions that are used by the `surge.materials` and `segments` subpackages. It includes representations of instrumental actions, parameter envelopes, special data structures, graphics utilities, "handlers" that apply actions and envelopes to rhythmic structures to create specialized instrumental notation, "makers" that deploy generative algorithms to create musical structures, miscellaneous rhythm utilities and templates that generate various parts of the score architecture.

5.1 Abjad and Lilypond

Since it is an integral part of the `surge` software package, it is important to introduce Abjad. This open-source Python package is designed for what the authors call "formalized score control" [Baça et al., 2015]. It provides composers with an object-oriented model of Common Practice Music notation. Software developed with Abjad is capable of programmatically constructing arbitrarily complex scores and typesetting them using Abjad's interface to LilyPond.

Abjad's notation classes can be grouped into three broad categories: "components", "spanners", and "indicators". Components are the building blocks of a score, and can be hierarchically combined. The lowest level components, called "leaves", include `Rest`, `Note`, and `Chord`, which can be grouped inside "container" components like `Tuplet` and `Measure`. `Voice` is a higher level container, which sequentially organizes lower level containers and leaves. `Staff` containers can include multiple parallel voices, or can be used as sequences of containers and leaves. Spanner objects are attached to sequences of components and include things like slurs, piano pedalling brackets and dynamics hairpins. Indicators provide textual and symbolic markup on components. Examples of indicators are articulations (e.g. *staccato*, accents), tempo markings, and dynamic markings (e.g. *forte*, *pianissimo*). Taken together these classes provide the composer a complete toolkit to build a logically coherent and consistent score structure.

LilyPond is responsible for parsing the score markup file generated by Abjad and laying out graphical score components on a page. Stylesheets control how this is done. The concept of an override is important to how the `surge` software package is able to achieve non-traditional notation. LilyPond grobs (graphical objects) are representations of score elements. They include staves, notes, flags, beams, clefs, bar lines, etc. Each grob has a number of properties that can be overridden: either directly in the LilyPond input file on an individual, temporary basis; or more globally in a stylesheet. Abjad provides an interface to these overrides so they can be created programmatically.

5.2 Modeling Form, Instrumental Actions, Notation and Composition Processes in the Surge Package

Form

Defined in the materials package, the formal divisions of each segment (stage and section) are represented as nested Python lists, with Abjad's `TimeSignature` objects at the lowest level. There is one time signature for every measure (even adjacent measures with equal time signatures). The form of a segment is described by list of stages. A stage is a list of sections and a section is a list of time signatures.

Segment II maintains a single tempo for its duration. The first segment though, has a different tempo for every section. Tempo changes are represented as a list of tuples, where the first element is an integer representing measure number, and the second element is a Abjad `MetronomeMark` indicator.

Instrumental Actions and Discrete and Continuous Parameters

All discrete parameters are declared as lists of lists, where each sublist corresponds to a stage. Every second-level list contains a sequence of primitive data types or instances of custom classes. The sequence is interpreted as cyclical by a handler class. In other words, sequences are repeated as needed.

The `WoodwindFingering` class models a fingering configuration for one of the two hands involved in woodwind instrument sound production. It stores a dictionary that maps a finger name to a key name, the name of the intended instrument and the

Instrument Category	Parameter Name	Data Type
(All)	Staccato	Boolean
Woodwind	Fingering	`WoodwindFingering`
Woodwind	Fingering combination	`WoodwindFingeringCombination`
Guitar	Fret placement	`FretPlacement`
Guitar	Fret combination	`FretCombination`
Guitar/bowed string	String index	Integer
Guitar/bowed string	Tremolo	Boolean

Table 5.1: Discrete parameters

name of the intended hand. It provides public methods to present the fingering as a binary list, create Abjad `Markup` indicators for a given key, show key options available to the given instrument, and utilities to facilitate the creation of `WoodwindFingering` objects. The `WoodwindFingeringCombination` class combines two `WoodwindFingering` objects to model a complete representation of a key configuration for a woodwind instrument. It allows the user to store the pitch or pitches the fingering combination is intended to produce.

The `FretPlacement` class applies to the guitar. It maps a single finger to a location on the fretboard, whose coordinates are string number and fret number. It has a Boolean property representing whether the pressure applied to by the finger is light enough to produce a harmonic or heavy enough to stop the string behind the fret. It is not necessary that a fret location coincides with a harmonic node of the string. The `FretCombination` class aggregates one or more `FretPlacement` objects to represent a particular guitar fretting.

Continuous parameters change smoothly over time. In `surge` they indicate changes in position along an axis or changes in various kinds of pressure. They are represented by the classes `BezierCurve` and `Path`. The `BezierCurve` represents a curved line segment. It is defined by a series of two or more control points. The outermost points represent the ends of the line segment and the inner points define the nature of the curve. The more control points to a curve, the higher its degree. Its `__call__` method is a lookup that returns a Y value for a given X value. `BezierCurve` objects are linked together in a `Path` object.

Instrument Category	Component	Parameter
Woodwind	Air support	Pressure
Woodwind	Embouchure	Pressure
Guitar	Picking	Force
Guitar	Picking	Position
Bowed string	Fingering	Pressure
Bowed string	Fingering	Position
Bowed string	Bowing	Pressure
Bowed string	Bowing	Position

Table 5.2: Continuous parameters

Notation

Template classes create an empty score structure. Music maker classes create rhythm-only `Voices` according to rhythm maker classes and a list of time signatures.

Music handler classes transform the rhythm voices by adding pitch data, indicators and grob overrides. The `SegmentMaker` class fills the empty score by calling music handlers.

A `Score` contains staves and staff groups. There is one staff group for each instrument. Template classes defined in the `surge.tools` subpackage generate staff groups appropriate for a given instrument category. The `ScoreTemplate` class generates a score object with staff groups based on a list of instrument names. There are four different kinds of staves. Time signature staves simply show time signatures and metronome markings. Rhythm staves display only rhythmic notation, with noteheads, barlines and staff lines hidden. Tablature staves show fingerings for guitar and wind instruments. Finally, continuous parameter envelope staves show `Path` and `BezierCurve` objects as line segments.

The `WoodwindFingeringHandler` and `GuitarFrettingHandler` classes create markup for tablature staves. They handle notehead glyph creation and positioning. Notehead placement involves mapping an index of some kind to a staff line. In tablature, rather than providing a ruler that demarcates pitch intervals, staff lines represent an aspect of the mechanics of an instrument. In guitar tablature, a staff line represents a string and in woodwind tablature it represents a finger.

Composition Processes (Classes, Functions, and Code Fragments)

Time Subdivision Strategy - Recursive Bifurcation

The form of Segment I is determined in a top-down manner (this will be discussed in the next chapter). According to this strategy, large chunks of time are recursively subdivided into ever smaller pieces. The function that performs this operation, `bifurcate_duration`, is located in the `surge.tools.rhythmtools` subpackage. It depends on another algorithm called `partition_integer_into_halves` which is adapted from a function from Abjad.

Rhythm Makers

Perhaps the most important generative algorithm used in `surge` is Abjad's `RhythmMaker` class and its subclasses. A rhythm maker accepts a list of time divisions specified as fractions of a whole note. For each division, it produces one or more leaves such that the sum of leaf durations equal that of the division. A rhythm maker may produce notes or rests. The output of a rhythm can be inserted into containers such as measures, voices and staves. The durations of the output may also be used as an input to another rhythm maker. All notes produced by a rhythm maker have their pitch set to middle C. These notes could be further transformed, for example, changing their pitches or transforming them into chords. Classes that inherit from `RhythmMaker` implement different strategies for generating rhythm data.

`NoteRhythmMaker` creates a single note (or a group of tied notes) whose durations are equal to the division durations. `TaleaRhythmMaker` accepts an additive rhythm, represented as a list of integer durations representing multiples of a unit pulse as a parameter. If the duration of the `Talea` is longer than sum of the division durations, it is truncated. If it is shorter, `TaleaRhythmMaker` repeats the talea until it is longer, then truncates if necessary. `TupletRhythmMaker` takes a list of tuplet ratios as a parameter and subdivides the input divisions according to each. A tuplet ratio is simply a list of integers representing the proportions of subdivided durations. If there are fewer ratios than divisions, then ratio list is repeated. For example a ratio of [2, 1, 1, 1] applied to a measure of $\frac{2}{4}$ would produce an eighth-note quintuplet containing a quarter note and three eighth notes.

There is a collection of classes in the `surge` package designed to be used in conjunction with the `TupletRhythmMaker` class. These classes generate ratios or patterns of ratios to serve as input parameter for the rhythm maker. The `RatioMaker` class is instantiated with a `Subdivider` object and a list of divisions, which are also to be provided to the `TupletRhythmMaker`. Classes that subclass `Subdivider` implement different strategies to generate a ratio.

Masking with Ties and Rests

With default settings, the output of a rhythm maker is simply a sequence of notes. To add more complexity to the output, one may use input masks to transform the note sequences in various ways. Masks are used as parameters to a rhythm maker. There are two masks available in Abjad: `SilenceMask` and `SustainMask`. Masks accept a cyclic list of mask indices and cycle period. As a rhythm maker creates a note, it compares its index against the current index in the mask cycle and transforms the note based on the type of mask. If a silence mask is supplied, the note is turned into a rest. If a sustain mask is supplied, it ties the note to the previous note. When the rhythm maker moves onto the next note, the mask index is incremented. Silence and sustain masks can be used simultaneously.

Chapter 6

Composition

6.1 Introduction

Motion is portrayed in *Heave, Sway, Surge* by manipulating some form of perceptual pressure or tension. One way is through instantaneous tempo changes. A clearly established tempo that unexpectedly modulates to another tempo creates a distinctly forceful effect. Another is the regulation of vertical and temporal density. Yet another method of manipulating pressure to create a feeling of movement relies on the continuous rise and fall of multiple simultaneous pitches in different voices. Motion is also suggested through the tension caused by superimposing different pulse rates against a steady pulse.

Form

For *Heave, Sway, Surge*, I use specific terms for various hierarchical levels of form. At the highest level, the piece is divided into two "segments." These are analogous to what is normally called a movement in other compositions [1]. The boundary between segments is a short break for the musicians to prepare for the next segment. The duration of this break is indeterminate, yet shouldn't be much longer than a minute or two.

The formal division below the segment is called a "stage". Its significance varies between segments one and two, but generally it establishes and sustains for its duration a definitive texture or combination of textures for a group of instruments. Below the stage level are "section" and "subsection." What these terms signify is different for each segment.

Texture

Texture is ordinarily a nebulous term (especially when discussing contemporary chamber music). It usually refers to the way rhythmic, melodic and harmonic materials are combined and the net effect of their combination, a reductive quality of a musical moment or passage. Sometimes a musical texture is defined by such properties as the number of distinct musical voices and attack density, and maximum pitch range.

[1] The term "movement" felt too strongly associated with classical forms like the symphony or string quartet. To me it implied a rhetorical or narrative-like approach to form that is tied to tonal harmony. While I think labeling this formal division as a movement would have been reasonable and adequate, "segment" felt more stylistically neutral and without any expectations of what the formal division should accomplish.

Traditionally, texture is talked about in terms of the relation between a primary melodic line and its accompaniment (e.g. monophony/polyphony, homophony/heterophony).

In *Heave, Sway, Surge*, texture plays a concretely defined role. Its definition retains the idea of a distinct, consistent quality of a stretch of music but it also represents a configuration of parameters for music-generating software functions. This configuration persists for the duration of a formal division. There are five basic textures, labeled with the Greek letters alpha, beta, gamma, delta and epsilon. Each texture consists of rhythm makers, masks, envelopes, and patterns of discrete parameters for the instruments assigned to the division. Decisions about a textural configuration are guided by higher-level parameters such as temporal density, rhythmic regularity, and pitch center.

All rhythms in *Heave, Sway, Surge* are created with Abjad's rhythm maker classes. Rhythm makers are configured with division masks, tie vectors, specifiers, taleas and tuplet ratios.

There is an element of pitch organization in *Heave, Sway, Surge*, though its role is not complex. The tonality of the work is based on the scordatura of the guitars. From the lowest to the highest, the guitar strings are tuned to E, A, C, F, A, and E. The tuning suggests A minor triads and F major triads, and other pitches in the piece reinforce a C major or A minor tonality. However, there are no strongly tonal functional relations between pitches expressed in the ensemble. The tonality of the piece might be described as pandiatonic.

6.2 Segment I

In Segment I, motion is conveyed primarily through instantaneous tempo changes. A transition between two clear tempi has a distinct cognitive effect. For me, it suggests the feeling of taking sharp turn at high speed in a car or ascending rapidly in airplane. These experience involve centripetal or gravitational forces that act on the body, to which the body responds and the mind perceives. This kind of shock seems analogous to how the mind adjusts to a change in tempo.

The tempo changes in Segment I are predetermined as part of a formal operation. As mentioned in chapter 5, the form of segment I is defined with assistance from a recursive bifurcation algorithm. There are five stages of 16 measures of $\frac{2}{4}$ at a tempo of 54 quarter notes per minute. Each section is subdivided into two, three, four, three, then two almost equal sections, according to the `bifurcate_duration` function. Figure 6.1 shows the stages and their section durations.

- stage 1: $\frac{33}{4}$, $\frac{31}{4}$
- stage 2: $\frac{22}{4}$, $\frac{21}{4}$, $\frac{21}{4}$
- stage 3: $\frac{17}{4}$, $\frac{16}{4}$, $\frac{17}{4}$, $\frac{15}{4}$
- stage 4: $\frac{21}{4}$, $\frac{21}{4}$, $\frac{22}{4}$
- stage 5: $\frac{31}{4}$, $\frac{33}{4}$

Figure 6.1: Section durations: *Heave, Sway, Surge*, segment I

Then, each section is re-conceived as a duration with a different fractionally related tempo such that the clock time of the new section equals the old one. Figure

6.2 shows these transformations.

Each section is then recursively subdivided using the same uneven bifurcation algorithm, yielding subsections around two to four measures in length.

There are three distinct textures in segment I: alpha (α), beta (β), and gamma (γ). Additionally, there are two variations on the gamma texture, labeled alpha prime (α') and alpha double prime (α''). These textures exist in the segment both superimposed and in isolation.

Label	Name	Instruments	Defining Characteristics
α	Ground	Guitars, strings	Constant pulse. High rhythmic regularity. low temporal density. Background to other activity. Short/staccato events.
β	Drone	Bass clarinet, bass	Low temporal density. Single pitch. Long/sustained events.
γ	Prism	all	Layers of similar patterns at different pulse rates. Low rhythmic regularity. High temporal density. Long, sustained events.

Table 6.1: Textures: *Heave, Sway, Surge*, segment I.

Regarding pitch, each stage is associated with a pitch class center. The pitch classes for each stage are A, E, F, C, A. The pitches occur mostly in the bass register, forming kind of a pedal point.

Texture Alpha

The α texture serves as a kind ground bass or ostinato underpinning the γ texture in the central C stage of the segment. It consists of only the pair of guitars. The texture is marked by a continuous eighth-note pulse in each guitar. The rhythm is gen-

- section 1-1: $\frac{33}{4}$ @ q=54 (1:1)
- section 1-2: $\frac{93}{8}$ @ q=81 (2:3)
- section 2-1: $\frac{55}{8}$ @ q=68 (4:5)
- section 2-2: $\frac{21}{4}$ @ q=54 (1:1)
- section 2-3: $\frac{63}{8}$ @ q=81 (2:3)
- section 3-1: $\frac{85}{16}$ @ q=68 (4:5)
- section 3-2: $\frac{7}{1}$ @ q=47 (8:7)
- section 3-3: $\frac{51}{8}$ @ q=81 (2:3)
- section 3-4: $\frac{7}{1}$ @ q=72 (3:4)
- section 4-1: $\frac{21}{4}$ @ q=54 (1:1)
- section 4-2: $\frac{105}{16}$ @ q=68 (4:5)
- section 4-3: $\frac{33}{8}$ @ q=81 (2:3)
- section 5-1: $\frac{155}{16}$ @ q=68 (4:5)
- section 5-2: $\frac{33}{4}$ @ q=54 (1:1)

Figure 6.2: Subsection durations and tempi: *Heave, Sway, Surge*, segment I

erated using an `EvenDivisionRhythmMaker`, which fills a division with an appropriate number of equal durations. The guitars use a constant, unaccented plucking force. The plucking position moves slowly from one extreme to the other (near the bridge to the edge of the fingerboard). The guitarists maintain a single fretting throughout the stage: the twelfth fret on the fourth string (which is tuned to C) with a harmonic-eliciting pressure (producing an F).

The piece opens with a variation on this texture (α'), presented alone at first, and then combined with the β texture in stage B. Again, the texture is defined by two guitars, with slowly moving plucking position and frettings based on harmonics. This variation replaces the constant pulse with an unmeasured tremolo plucking. The frettings are again based on single strings, but the string index and fret number change at measure downbeats.

The manner in which the fret/string locations change follows a simple alternating pattern that is reset at the beginning of every subsection. In the first bar, guitar I begins the tremolo while guitar II rests. In the second bar, guitar II enters, sometimes at the same location. Guitar II maintains the location into the third bar while guitar I moves to a new one. This pattern resembles fourth species counterpoint, a staggered note-against-note movement, but ignores the rules around resolving dissonances.

Pulse is inaudible in α'. Though fret and string changes occur at the measure downbeat, the unpredictability of measure lengths combined with the lack of rhythmic articulation apart from the unmeasured tremolo picking contributes to a weak sense of pulse. The tempo changes in A and B serve only to compress and expand time intervals of the fret and string changes.

The lack of pulse at stages A and B creates an opportunity for a powerful effect. At C a rigid pulse appears, seemingly out of nowhere. This sudden burst of energy suggests a rapid acceleration. After the listener has become entrained to the pulse at this tempo, instantaneous change in tempo at start of the next section creates a cognitive disturbance. This shock reminds me of taking a sharp corner in a fast car.

The stringed instruments take over for the guitars in the α'' texture at stage D. The pulse rate is doubled to sixteenth-notes. The violin, viola, cello and bass maintain a single fingering position, which, like the guitars is at the harmonic halfway down the string. For the violin, viola, and cello it is the fourth string (C). The bass has it on the first string (G). Like the guitars' plucking position in the α texture, the bowing position changes gradually between the extremes of the fingerboard and the bridge.

The texture is passed between the instruments of the string section, changing at every subsection. In the second and third sections, the instruments are progressively layered so that at the end of the stage, all four stringed instruments sound simultaneously.

Texture Beta

The β texture appears only in stage B alongside the α' texture. It relies on the bass clarinet and double bass to create a continuous drone-like effect, with dense and irregular articulations of a single pitch. The clarinet and bass never play at the same time, instead alternating every subsection.

The rhythms of texture β are created with a `TaleaRhythmMaker`. Each of the five parts, which includes bass fingering and bowing and clarinet embouchure, left hand fingering and right hand fingering, use sixteenth-notes as the unit pulse. The excitator components of each instrument (bowing and embouchure) share a talea of [17, 2, 2, 2, 2, 2, 1, 2, 3, 4, 5]. The bass fingering talea is [7, 6, 5, 6]. The taleas for the clarinet left and right hand fingerings are [7, 6] and [5, 6], respectively.

In the double bass part, the fingering and bowing are applied to the fourth string (E). The bowing position stays at a constant *sul ponticello* with light pressure. The fingering meanwhile slides between near the nut (where the string is effectively unstopped) and the location of the 3rd harmonic, in both directions. The finger pressure is light, such that only harmonics will sound. The effect is a soft, noisy, glissando through the upper extremities of the E harmonic series.

The combinations of left and right fingerings of the bass clarinet produce the pitches E3, F3, E4, and F4 (concert, not transposed). The nature of two fingering rhythms produces an irregular, unpredictable, multi-note trill between the four pitches. Concurrently, the activity in the embouchure adds another layer of rhythmic complexity. The air pressure and lip pressure envelopes slowly oscillate in sync from low to high, creating a sound that moves between soft and airy (maybe even without a clear pitch) to a full-bodied tone.

Texture Gamma

The γ texture occupies the foreground in stage C. Here it is produced by the bowed strings. In stage D, it is taken over by the winds, and finally by the guitars in stage E. Working from the idea of a prism, which refracts light rays through facets at various angles, this texture consists of layers of instruments performing similar materials at different rates of pulse.

At stage C, the strings perform harmonic glissandi with an even, constant, bowing rhythm. The texture here is partly defined by `TupletRhythmMaker` objects and the kinds of ratio patterns that are provided to them. The ratios that serve as parameters for the rhythm maker are generated by a `RatioMaker` object.

An `EvenSubdivider` generated the ratios for the `RatioMaker`, which simply splits the input duration into an even number of durations based on the provided prolation[2]. Here the prolation of each string part alternates every measure.

At stage D, the gamma texture is transferred to the three winds, where it is paired with the alpha prime texture in the strings. Much of the rhythm materials from the strings at C are reused here to define the texture. The tuplet maker, using the same ratios with alternating prolation that served to generate the bowing rhythms at C, is transposed to the embouchure rhythms of the winds at D. The taleas that supplied the talea rhythm maker for the string fingering rhythms at C are likewise adapted to the woodwind fingering rhythms at D.

[2]While the term "prolation" usually describes an aspect of mensural notation in medieval and Renaissance music, the creators of Abjad use it to describe the scaling factor used to compress or stretch the durations inside a tuplet. It is sometimes notated as a ratio of the form a:b inside a tuplet bracket.

The rhythmic profile of woodwind fingerings are also similar to that of the bass clarinet in the β texture at stage B. However, the left and right fingerings for each instrument are chosen so that their combinations yield a larger set of pitch classes.

In the final stage, the two guitars, unaccompanied, take on the γ texture. Tuplet rhythm makers, again with alternating prolation, provide the fingering rhythms. Both guitars use a repeating fingering pattern and sustain a single fret combination for the duration of the stage. The guitarists arpeggiate a first-inversion F major seventh chord. Their pulse rates rarely align and the fingering patterns are not coordinated with downbeats.

While composing this stage, I was reminded of a a computer animation from 1978 called "The Hypercube: Projections and Slicing", where a four-dimensional cube is projected into a three-dimensional space and rotated [Banchoff, 2000]. As the animation unfolds, one sees the sides of the hypercube revolve around its center and change size. The experience is at the same time uncanny and familiar.

6.3 Segment II

Segment II conveys motion in a different way than in Segment I. It uses changes in density as a means to create musical tension. Intensity increases as layers of material are accumulated and events are gradually brought closer together in time. In the first two stages of Segment II, movement is telegraphed through the changing pitches of the strings.

The segment is marked by a different approach to form, meter, tempo and texture. Rather than subdivide a predetermined duration, the form of segment II is constructed by concatenating seven stages of equal duration (35 measures each). The time signature remains a constant two-four time and the tempo is fixed at 60 beats per minute.

Textures here are more monolithic. Whereas in segment I a texture was tied to an instrument group and subject to layering with other textures, a texture in segment II has a more global scope. It involves all of the instruments that are active for a given stage.

Another formal aspect that distinguishes this segment from segment I is that in segment II, textures were tightly coupled to instrument categories (winds, guitars, strings). For example, in segment I, stage C the guitars are assigned the α texture and the strings are assigned the γ texture. But in segment II, the texture for every stage is applied to the entire ensemble, although whole instrument categories rest for certain stages. Furthermore, stages E and F of segment II collects instruments into groups that cross instrument category. These groupings determine which instruments are active at which measures.

Texture Delta

The δ texture that opens segment II features only the bowed strings. The most salient feature is the coordinated movement of each voice's left hand position. The finger position envelopes are characterized by a simple pattern where the position moves from one point to another for a certain duration, then remains in place for another duration. Each instrument is assigned only its A string. The sustained positions are drawn randomly from a set of small whole number ratios, yielding just intervals.

The rhythm of the left hand for each instrument is the same. It is determined by a list of duration pairs, where the first duration corresponds to the moving part of the pattern and the second corresponds to the static portion. This list is flattened and used as a talea for a `TaleaRhythmMaker`.

The bowing rhythm, on the other hand, is different for each instrument in the string section. They are also independent and largely non-coincident with the fingering rhythm. The rhythms are additive. Pulse rates are constant and unique to each voice. The rhythms for the violin, viola, cello and bass constructed from units of sixteenth-note quintuplets, eighth-note triplets, eighth-note septuplets, and sixteenth-notes. The rhythms are lent proportional similarity through how the unit durations are fused to create additive rhythms through the use of sustain masks. The sustain masks are cyclic, and their periods range from seven to ten unit durations.

The bowing height envelopes resemble sine wave with a small amplitude, and their y-offsets move gradually from *sul tasto* to *sul ponticello*. The bowing pressure envelopes also have a sine shape, but with a shorter wavelength.

At stage B, the strings continue the δ texture, with the most significant alteration being that the fingering rhythms are no longer in unison. Each instrument is assigned a randomly shuffled version of the sequence of duration pairs used at stage A.

Texture Epsilon

The ϵ texture, which spans stages C through G, is more granular. It is comprised of rapid, short events; the vertical density and polyrhythmic nature of which contribute to something resembling micropolyphony. The texture evolves through each stage. This evolution occurs in the instrumentation, the grouping of instruments, and the temporal density of instrument groups as the stage progresses. Table 6.2 shows this evolution. The accumulation of layers creates an increase in vertical density, which is paired with an increasing temporal density.

The table shows, for each stage, a description of the textural components for each instrument category, as well as how silence masks are applied to the instruments of the ensemble in terms of how they are grouped together. The content in instrument category columns are higher level descriptions of rhythmic profiles and other materials used in part generation. The silence mask groups column shows the instruments that share silence mask settings in their respective rhythm makers.

The designations heterorhythmic and polyrhythmic describe how the rhythms of the instruments within the category relate to each other. If a group is marked as heterorhythmic, their rhythms share a common pulse rate, but the onsets and durations will be different If a group is marked polyrhythmic, the rhythms in each of the parts will have different pulse rates.

Silence masks, which are configured for use in a rhythm maker, control which input divisions in a rhythm maker should be cleared of data after rhythm generation.

Stage	Winds	Guitars	Strings	Silence Mask Groups
C	Polyrhythmic; fingering: rhythmically regular multiphonic trills; embouchure: volatile air/lip pressure changes, staccato, irregular	tacet	Polyrhythmic; fingering: volatile pressure/height; bowing: volatile pressure/height, staccato;	(ob, cl, sax), (vn), (va), (vc), (cb)
D	like C	Heterorhythmic; fingering: static harmonic chord; plucking: tremolo, forceful, one string at a time, changing position	tacet	(ob), (cl), (sax), (gtr1), (gtr2)
E	like C	like D	like C	(ob, gtr1, vn), (cl, va), (sax, vc), (cb, g2)
F	like C	like D	like C	(ob, cb), (cl, vc, gtr1), (sax, va), (gtr2, vn)
G	tacet	Polyrhythmic, fingering at half-stopped pressure, discrete glissando from 1st fret to 18th; plucking: like D, no tremolo, decreasing force	tacet	(gtr1), (gtr2)

Table 6.2: Textures: *Heave, Sway, Surge*, segment II.

In the context of *Heave, Sway, Surge*, it effectively erases measures. It is used to control vertical density at the measure level. Instruments within a silence mask group will have the same measures erased.

Chapter 7

Conclusion

The final version of *Heave, Sway, Surge* is a significant revision of a version completed in May of 2015. This first version consisted of a single segment, which became the first of two in the final version. The segment in each version is structurally identical to the other in that it has the same number of measures, same time signatures, same tempo changes and same proportions in its subdivisions. What differs is the content of the measures – the materials.

7.1 Evaluation: Version One

I made a recording of the first version in the same month of its completion. The participants (ensemble, conductor, recording staff) consisted of members of sfSound, UCSC students and independent music professionals. The recording was made at UC Santa Cruz, in the Electronic Music Studios.

I was only partially satisfied with the results. It wasn't a matter of poor performance. The musicians played wonderfully. The problems I had with the piece had to do with compositional choices and notation.

The biggest issue was the overall flow of the piece. The guitar introduction set a strong mood. The next texture, a translucent pad created by the winds and superimposed over the guitars complimented and enhanced the introductory texture. However, over the course of the piece, successive textural layers and changes detracted and distracted from the strong mood established at the beginning. Some of the textures went on too long and some changes in texture weren't as a drastic as I had intended them to be.

Also, the textures of the winds and strings weren't as effective as I imagined they would be. There was too much flux for too long. In the woodwinds, the fingerings were too numerous and their sequences were too complex and unpatterned. The intended multiphonics of some of the fingerings never materialized. This complexity in the fingerings, combined with more complexity in the embouchure parts, yielded figuration and gesture that felt arbitrary and directionless, with little correspondence between the instruments in the wind section.

The string parts felt similarly unfocused. The bow and finger height envelopes were randomly generated with continuously changing range constraints. They seemed arbitrary, with no clear intention.

The original instrumentation included trombone. The recording made it clear that the trombone didn't blend with the rest of the ensemble. It was removed in the second draft.

7.2 Evaluation: Version Two

The second version of *Heave, Sway, Surge* was completed in February of 2019 and a recording took place in the same month. Many of the players from the first recording returned. The recording of the second version aligned more closely with my imagination. Certain aspects of it were more controlled and predictable. I was also pleasantly surprised by the way the textures took shape as well as the choices made by the musicians.

7.3 Future Software Projects

The process of composing *Heave, Sway, Surge* has given me many opportunities to reflect on improvements and future avenues of research, development and composition. The most glaring flaw of my notation system is that the envelope staff is only able to represent one continuous parameter per event. This is due to a limitation of LilyPond. The notation would be more powerful and compact if it could encode multiple continuous parameters. One encoding might represent changes of a value by having the color "change" over time, as in a horizontal gradient. Another is that the thickness of the line could change. Figure 7.1 imagines how such encodings might look.

A more intuitive woodwind tablature might rely on instrument-specific fingering diagrams. Figure 7.2 shows an oboe fingering staff where the fingerings for each hand are shown separately. The musician would be able to see a straightforward representation of which keys are supposed to be depressed, without having to be told which

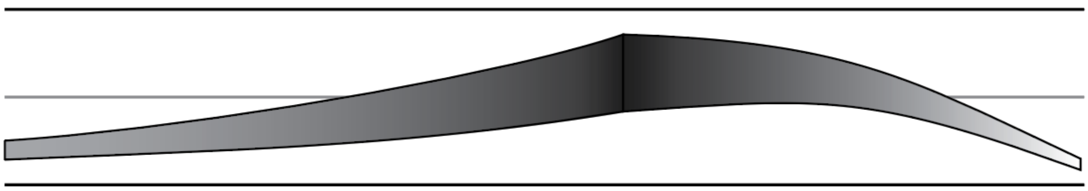


Figure 7.1: Enhanced envelope staff: color and thickness as secondary continuous parameters.

finger to use for which key, and without having to parse textual representations of key names.

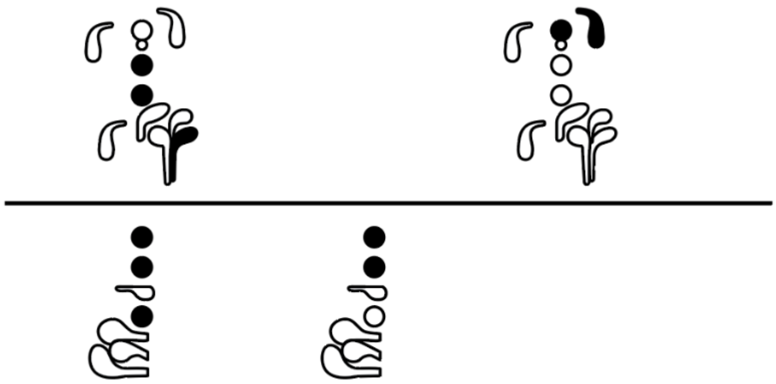


Figure 7.2: Enhanced oboe tablature staff: key diagrams.

A major drawback of the software system I designed is that the cycle of coding, composition and rendering is very slow. It required careful planning and tedious programming. Rendering the complete score takes about twenty minutes. Although I made it possible to render portions of the score to check the results before making revisions, the long iteration time made it difficult to develop a creative momentum.

As powerful and flexible as they are, Abjad and Lilypond are prevent me from addressing these drawbacks. I envision an application with four major components: a generic model of musical logic, a score renderer, a graphical user interface, and an audio rendering engine based on physical modeling synthesis.

This system would allow a composer to define an event type as a collection of continuous and discrete parameters associated with a specific instrument. With definitions in place, the composer could create sequences of events through a visual editor and see an immediate score representation. They would also be able to play back the score, with the software interpreting the event lists as instructions to a physical modeling synthesizer, and hear a prediction of what the events might sound like on a real instrument.

7.4 Future Compositions

In future compositions, I'd like to remove the constraint established in *Heave, Sway, Surge* of creating sound mass textures, and focus more narrowly on individual instruments, in solo pieces or works for a smaller ensemble. Doing so would allow me to explore in more depth the interaction of performance parameters and their sonic results.

The models of instrumental performance created for *Heave, Sway, Surge* were limited. They focused on traditional methods of sound production. The woodwinds were limited to established embouchure techniques and the keying mechanisms. The guitars used normal fretting and plucking techniques. The bowed instruments focused on the bowed string stopped by fingers.

I'd like expand the performance spaces involved. Each instrument provides more opportunities to define alternate excitator and resonance modulators. For example, on a bowed string instrument, the player's left hand, in addition to stopping a string, can serve as an excitator. It can strike various surfaces on the instrument such as the top and sides of the body. Similarly the bow can be applied to surfaces like the bridge, the body and tailpiece.

* * *

The process of developing the *Heave, Sway, Surge* software and its composition was deeply informative and enriching. For me, it raised many questions about the fundamentals of instrumental performance, musical material, form and interpretation. I look forward to exploring these questions in future work.

Bibliography

[Baça et al., 2015] Baça, T., Oberholtzer, J. W., Treviño, J., and Adán, V. (2015). Abjad: An open-software system for formalized score control.

[Banchoff, 2000] Banchoff, T. (2000). The hypercube: projections and slicing.

[Bernard, 1994] Bernard, J. W. (1994). Voice leading as a spatial function in the music of ligeti. *Music Analysis*, 13(2/3):227–53.

[Brown, 2008] Brown, E. (2008). On *December 1952*. *American Music*, 26(1):1–12.

[Cassidy, 2013] Cassidy, A. (2013). Constraint schemata, multi-axis movement modeling, and unified, multi-parametric notation for strings and voices. *Search: Journal for New Music and Culture*, 10:1–24.

[Hübler, 1984] Hübler, K. K. (1984). Expanding the string technique. *Interface*, 13(4):187–198.

[Karplus and Strong, 1983] Karplus, K. and Strong, A. (1983). Digital synthesis of plucked-string and drum timbres. *Computer Music Journal*, 7(2):43–55.

[Lachenmann, 1970] Lachenmann, H. (1970). Klangtypen der neuen musik. *Zeitschrift für Musiktheorie*, 1(1):20–30.

[Pace, 2008] Pace, I. (2008). Positive or negative 1. *The Musical Times*, 139(1859):9–17.

[Pritchett, 2009] Pritchett, J. (2009). *The Music of John Cage*. Cambridge Univ. Press, Cambridge.

Part II

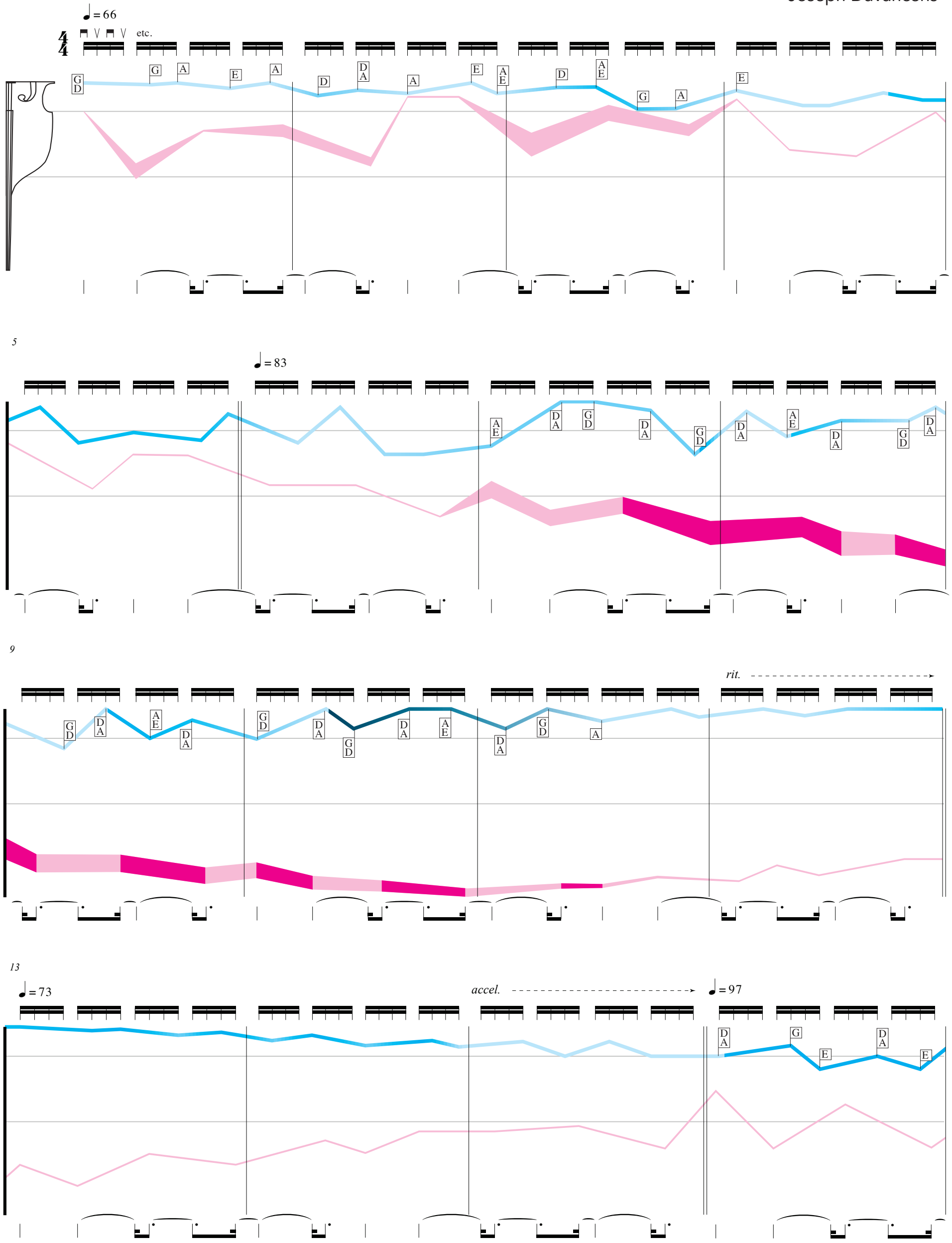
Appendix

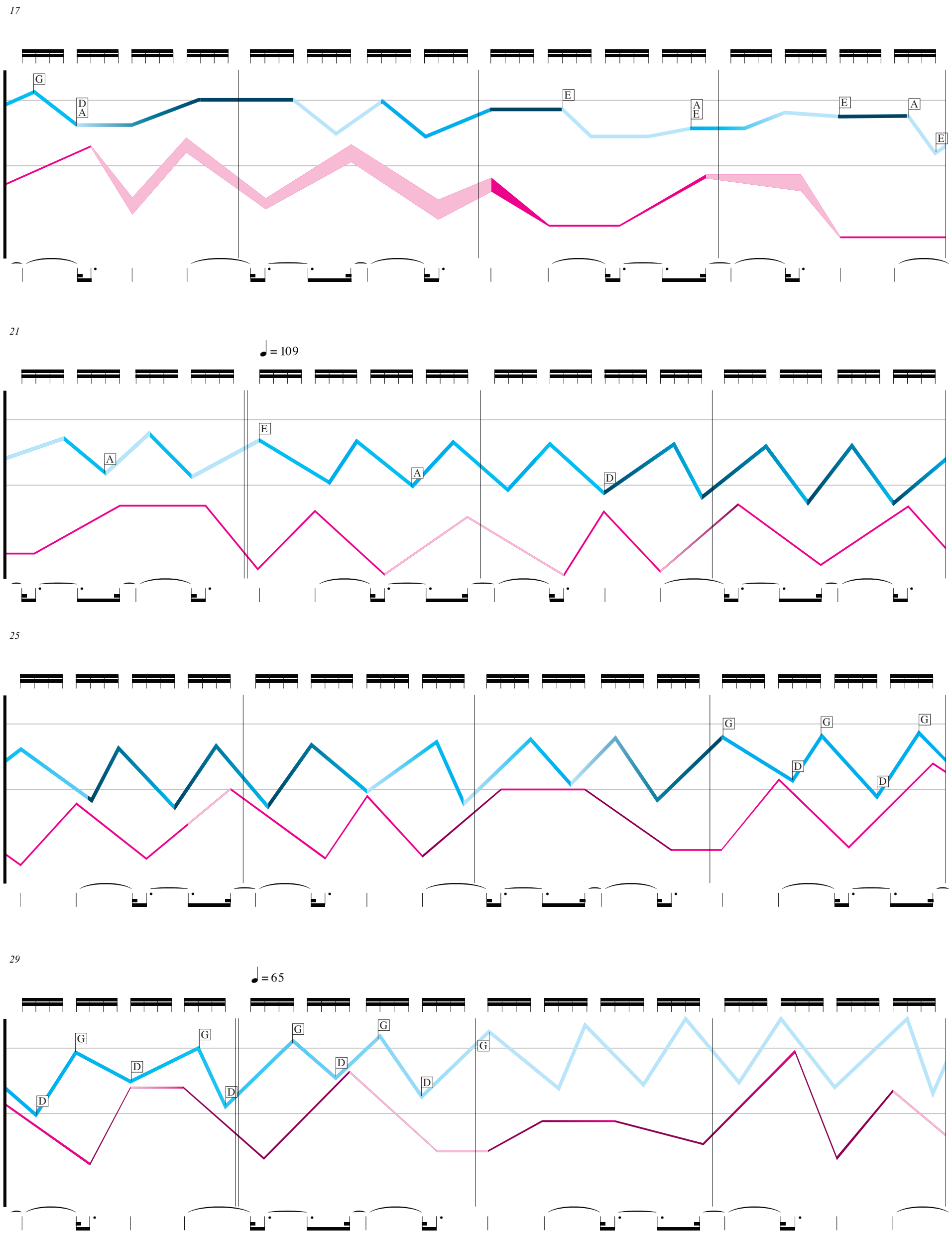
Appendix A

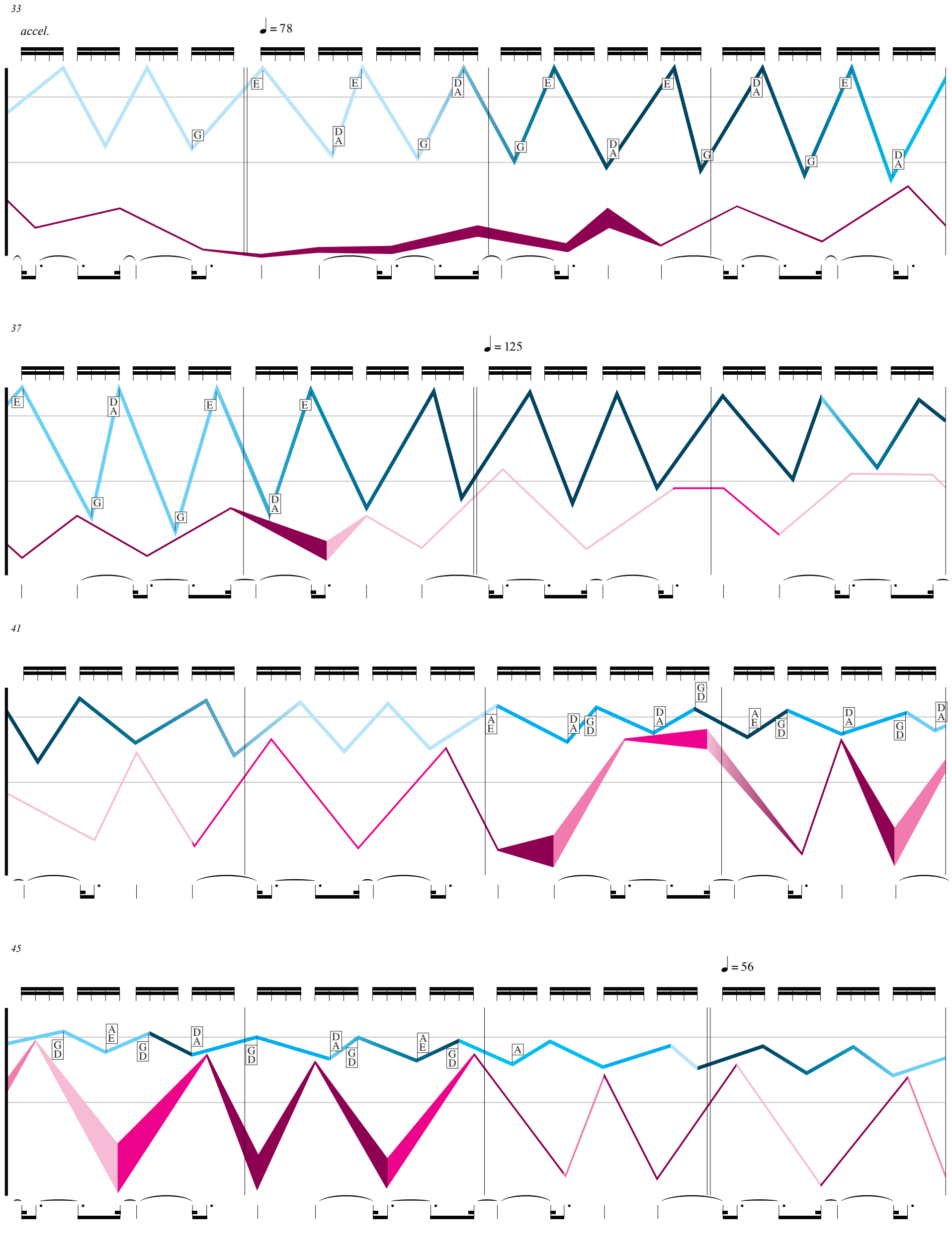
Study for Double Bass

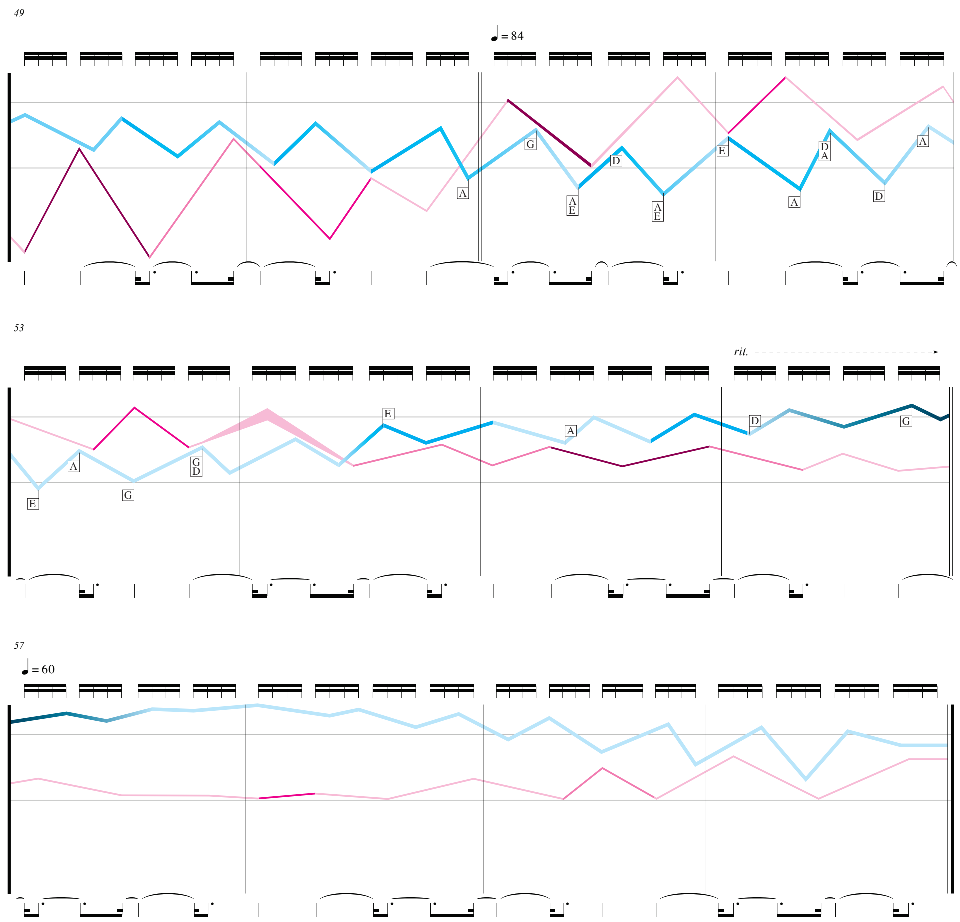
Study for Double Bass

Joseph Davancens




17
G
D
A
E
A
E
E
A
E
21
♩ = 109
A
E
A
D
25
G
D
G
D
G
29
♩ = 65
D
G
D
G
D
G
D
G
D
G


33
accel.
♩= 78
37
♩= 125
41
45
♩= 56


49
♩ = 84
A
G
A E
D
A E
E
D A
A
D
A
53
rit.
E
A
G
G D
E
A
D
G
57
♩ = 60