UNIVERSITY OF CALIFORNIA

Santa Barbara

Part One:

Compositional Utilization of Sensory Dissonance

Part Two:

A Portfolio of Compositions

A dissertation in partial satisfaction of the

requirements for the degree Doctor of Philosophy in Music

by

Brian Michael Hansen

Committee in charge:

Professor Clarence Barlow, Chair

Professor Curtis Roads

Professor Joel Feigin

September 2013

The dissertation of Brian Michael Hansen is approved.

Joel Feigin

Curtis Roads

Clarence Barlow, Committee Chair

September 2013

Part One:

Compositional Utilization of Sensory Dissonance

Part Two:

A Portfolio of Compositions

Copyright © 2013

by

Brian Michael Hansen

ACKNOWLEDGEMENTS

I would like to thank my committee members, Dr. Joel Feigin, Dr. Curtis Roads, and Professor Clarence Barlow, chair, for their support, guidance, and friendship given to me. Thank you Joel for always lending a critical eye to my work and challenging my compositional craftsmanship. Thank you Curtis for helping to guide my artistic aesthetic and in particular the term “economy of selection”. Thank you Clarence for showing me how to harness my creative potential lying in the mix of art, science, and engineering. Finally, a special thank you to my wife, LaRae, and our daughter, Emma, for their enduring love and support. I truly could not have accomplished this without you.

VITA OF BRIAN MICHAEL HANSEN
September 2013

EDUCATION

Bachelor of Arts in Music and Mathematics, University of Saint Thomas, St. Paul MN, May 2001

Master of Science in Multimedia Engineering, University of California, Santa Barbara, March 2012

Doctor of Philosophy in Music, University of California, Santa Barbara, September 2013 (expected)

PROFESSIONAL EMPLOYMENT

2012 – 2013: Software Contracting, Slate Pro Audio RAVEN multi-touch production console, Hollywood CA

2010 – 2012: Music Technology and Composition consultant, Music Mastermind Inc., Calabasas CA

Winter 2011: Course Instructor, University of California, Santa Barbara

2010 – 2011: Teaching Assistant, University of California, Santa Barbara

Fall 2008: Course Instructor, University of Minnesota, Minneapolis

AWARDS

Corwin Electro-Acoustic Music Competition, 1st prize, University of California Santa Barbara, 2010

Corwin Ensemble Music Competition, 3rd prize, University of California Santa Barbara, 2010

Fricker Fellowship, Department of Music, University of California Santa Barbara, 2008–2010

University Central Fellowship, University of California Santa Barbara, 2007

Subito grant, American Composers Forum, 2005

PUBLICATIONS

Hansen, Brian & Shakiban, Cheri. “Exploring Fractal Geometry in Music”, Bridges: Mathematical Connections in Art, Music, and Science Conference Proceedings, Towson, Maryland, 2002

FIELDS OF STUDY

Major Field: Music Composition

Studies in Music Composition with Professor Clarence Barlow, Professor Joel Feigin, and Professor Curtis Roads

Studies in Multimedia Engineering with Stephen Travis Pope and Dr. Mathew Wright

ABSTRACT

Part One:

Compositional Utilization of Sensory Dissonance

Part Two:

A Portfolio of Compositions

by

Brian Michael Hansen

Part One:

This document will present the calculation of sensory dissonance and its potential structural implications for music composition. The goal is to present tools and approaches that can serve composers and theorists in their endeavors to create and understand music. It will accomplish this by demonstrating how the calculation of sensory dissonance can be used to model sonic and compositional structures in the timbral, harmonic, and spatial domains.

Part Two:

A Portfolio of Compositions

A portfolio of compositions, including scores of

- *Binated Triphasis* for sextet comprised of two bass clarinets in Bb, two bassoons, and two horns in F

- *Activity and Presence* for cello and computer

- *the sky* for voice and computer

- *Completion of J.S. Bach's Contrapunctus IV from The Art of the Fugue*

- *Studies of Sonic Process* for player piano and computer

A compact disk including

- *Activity and Presence* as performed by Katherine Mendenhall and Brian Hansen

- *the sky* as performed by Katherine Saxon and Brian Hansen

- *Studies of Sonic Process* as performed by Brian Hansen

- *A Family Portrait* for fixed electronics

- *San Viento* for fixed electronics

- *Drops: Popping Drains and Lapping Waves* for fixed electronics

- *sinophonme* for fixed electronics

A DVD including

- *Arch* a virtual sonic sculpture

- *Sensations of Tone* an interactive audio-visual installation

TABLE OF CONTENTS

Part One:

I. Introduction…….. 1

II. Calculating Sensory Dissonance With Spatial Considerations…….. 3

A. Core Calculation……..… 3

B. Incorporating Factors of Physical Space ……...……. 5

C. Inverse-Square Law……... 8

D. Atmospheric Absorption……..… 9

E. Phase……..…… 10

F. Auditory Masking……..…. 12

G. Equal-Loudness Contours…… 13

III. Sonic Applications of the Spatial Calculation…… 14

A. Creating and Visualizing a Dissonance Field…… 14

B. Immersive Environments and Sonic Sculpture……. 18

IV. Harmonic Implications of Sensory Dissonance…… 20

A. Background…… 20

B. Harmonic Potential and *sinophonme*……. 22

V. Controlling Sonic Roughness and *Sensations of Tone*…… 27

VI. Conclusion……...….. 32

References……... 33

Part Two:

I. *Binated Triphasis*…….. 36

II. *Activity and Presence*……. 59

III. *the sky*……. 75

IV. *Studies of Sonic Process*……..… 84

V. Completion of J.S. Bach's *Contrapunctus XIV* from *The Art of Fugue*…… 92

VI. *San Viento*…… 112

VII. A *Family Portrait*……. 113

VIII. *Drops: Popping Drains and Lapping Waves*……. 114

IX. *sinophonme*…….. 115

X. *Arch*…… 116

XI. *Sensations of Tone*……. 119

LIST OF FIGURES

Figure 1. Notes constituting the dissonance field…….. 15

Figure 2. A dissonance field in the virtual space as represented by isosurfacing. Lower levels of dissonance are pictured in the top row, the highest levels in the bottom row…… 17

Figure 3. Two sonic sculptures: Curl (left) and Arch (right)…….. 20

Figure 4. A dissonance curve corresponding to intervals……. 21

Figure 5. Spectral makeup of a complex tone in *sinophonme*……. 24

Figure 6. The dissonance curve resulting from complex tones used in *sinophonme*…….. 25

Figure 7. Scale tone makeup of *sinophonme*……. 25

Figure 8. Fundamental frequencies of pitches used in *sinophonme*……..… 26

Figure 9. The Permutation Matrix in Contrapunctus XIV. "The permutation matrix in Contrapunctus XIV (J. S. Bach: The Art of Fugue)." Wikipedia. Wikimedia Foundation, Inc., Web. 19 Aug. 2013. <http://https://en.wikipedia.org/wiki/File:Permutation_matrix_web.png>…… 92

Figure 10. Placement of the sound sources for *Arch*……..… 117

Figure 11. The dissonance field producing the *Arch* sculpture…….. 118

Figure 12. Interface for controlling parameters of *Sensations of Tone*…… 120

Figure 13. Main control center for *Sensations of Tone*……... 121

I. Introduction

Historically, there have been numerous perspectives on how to define consonance and dissonance. Such perspectives span multiple contexts of culture, history, and science, and have yet to achieve universal agreement. As indicated by Richard Parncutt [17], it has always been fundamentally problematic to distinguish the cultural or learned ("top-down") vs. the innate or sensory ("bottom-up") aspects of what consonance is. He claims the boundary between the sensory and cultural is not clearly defined and depends on its operational definition. It is difficult to determine the boundaries of culture because of a lack of study and data related to the issue. In turn, this may impact the scientific or "bottom-up," in that the quantifiable component of dissonance in a musical sonority, sensory dissonance or "roughness," is potentially contaminated by the experiences and preferences of the listeners.

In addition to the philosophical questions surrounding consonance vs. dissonance, there have been historical attempts to quantify it. Pythagoras has been credited with the first attempt sometime in the sixth century BC, claiming tones related by simple frequency ratios are more consonant. Around 1638, Galileo Galilei made claims about the eardrum's response to sound. In support of the Pythagorean view, he claimed that simple ratios produce regular vibrations on the eardrum, and more complex ratios produce irregular motions, yielding more - or less - pleasant sounds respectively. In 1863, Hermann von Helmholtz's *On the Sensations of Tone* presented the ear as a

spectral analyzer, positing that the ear recognizes when two complex tones share harmonics, and tones sharing more harmonics are more consonant than tones not sharing any at all. More recently, in 1965 Plomp and Levelt more deeply explored the ideas set forth by Helmholtz and showed how dissonance could quantifiably be related to the subjective distance between two frequencies.

Plomp and levelt's results show that dissonance is a function of critical bandwidth. Critical bandwidth refers to the bandwidth of audio frequencies where if two tones lie within this bandwidth, the auditory mechanism cannot resolve them as unique. When two sine tones occupy the same critical band, beating (or roughness) in the sound is perceived. Plomp and Levelt defined the perceptual dissonance in a dyad by the severity of beating present, and they provide a response curve relating this definition of dissonance to the critical band. Upon defining this relationship, Plomp and Levelt went further to show that when applied to complex tones, they could produce dissonance curves that bear similarity with those produced by Helmholtz [18].

This type of dissonance, defined by the amount of beating or roughness present between two tones, has since been termed *sensory dissonance*. Through numerous studies, sensory dissonance has been shown to be highly correlative with Western common practices of music theory, and it has been successful in meaningfully modeling the phenomenon of dissonance in sonority. It is this type of dissonance, sensory dissonance,

which will serve as the exposition for the compositional explorations outlined in this document.

This document aims to explore potential compositional applications via the utilization of sensory dissonance. It will begin by first discussing the method and core calculation of sensory dissonance. Then, it will present how the calculation can be extended and adapted to suit different compositional needs. It will accomplish this by presenting how sensory dissonance can be applied to sound spatialization and the production of sonic environments, how it relates to harmonic hierarchy and the construction of musical scales, and how it can be utilized to generate and explore the intrinsic roughness and smoothness of a sonic spectrum.

II. Calculating Sensory Dissonance With Spatial Considerations

A. Core Calculation

Of the contemporary approaches to modeling sensory dissonance, there have been essentially two methods of approach in its quantification. The first was put forth by Kameoka and Kuriyagawa in 1969 which acknowledged the role of the critical band but did not utilize it. The second was implemented by Hutchinson and Knopoff in 1978 which fully utilized results from Plomp and Levelt and is thus based on the distance measured in terms of critical band (barks) between tones. A bark refers to the bark scale, a psychoacoustic-based scale ranging from 1 to 24 which corresponds to the first 24 critical

bands of hearing.

Between the two approaches, the Hutchinson Knopoff approach has been more widely utilized, as it has been shown to yield comparatively better results. The Hutchinson & Knopoff model calculates the dissonance of all combinations of dyads according to the Plomp & Levelt curve. Upon calculating the dissonance, it weights each dyad's contribution to a given spectrum's dissonance by computing the product of the two amplitudes of the dyad and dividing it by the sum squared of all amplitudes.

$$D = \frac{\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} A_i A_j g_{ij}}{\sum_{i=1}^{N} A_i^2} \tag{1}$$

where N is the number of partials, A_i represents the amplitude of a partial, and g_{ij} is the sensory dissonance of a given dyad based on the critical bandwidth between their frequencies.

The critical bandwidth dissonance input into the Hutchinson & Knopoff approach is calculated here by using Richard Parncutt's approximation of Plomp and Levelt's dissonance curve, yielding the dissonance for the dyad [15].

$$g(b) = \left(4b \cdot e^{-4b}\right)^2 \tag{2}$$

where b is the critical bandwidth distance as determined by the distance in barks between two tones.

Equations (1) and (2) serve as the core foundation for calculating sensory dissonance in the following compositional applications presented. These equations can be expanded, manipulated, and applied to various sonic and musical implementations. Each implementation, as described below, is unique in its utilization of sensory dissonance, reflecting a specific aesthetic influence and compositional practice.

B. Incorporating Factors of Physical Space

Sensory dissonance is of a highly physical nature, as at its core it is caused by the activity of actual atmospheric vibrations occurring at a particular point in space. If we imagine all the points in a particular space being shaped by the forces generated from sound sources, it is as if the atmosphere itself has been sculpted by the sound. Furthermore, if we consider an instant of music, it is precisely a snapshot of a particular state of the expansion/rarefaction occurring in the air. An entire piece of music then, listened to from beginning to end, is a sequence of these snapshots, a film yielding a dynamic sculpture of the atmosphere. If the atmosphere is essentially a sonic sculpture, what does it look like? Is there a meaningful visual representation of it, or is it limited to an auditory and psychoacoustic experience?

A work highly influential to this line of thought is La Monte Young's Dream House. Dream House, located in lower Manhattan, is a sound and

light installation, where the sound was designed by Young and the lighting by artist Marian Zazeela. The installation is set as a monochromatic room, sounding a single chord that has remained unchanged since 1993. The sustained chord encompasses a large portion of the acoustic spectrum ranging from extremely high to extremely low frequencies. The chord is spatially separated, as the different sinusoids of the chord emanate from multiple positions throughout the room. The overall effect is a completely immersive drone the listener can enter and explore. As the visitor navigates the room, the mix of sound changes based on their position and orientation. Certain tones are reinforced or attenuated, causing a morphology of harmony and melody for the visitor. The visitor is thus allowed to shape their own experience and form their own composition by how they choose to explore the space, or by how they subtly shift their orientation, simply tilting their head from side to side.

Works like Young's Dream House inspire questions about how a listener experiences spatialized sound. Although the space taken in its entirety consists of only the sound of a droning chord with each component remaining constant in frequency and amplitude, the listener has a dramatically different experience when entering the space. As the visitor navigates Dream House, they experience the reinforcement and attenuation of particular tones, causing the formation of unique sonic spectra particular to the visitor's perception. Such spectra are continuously changing as the visitor

moves about, and each one yields a unique level of sensory dissonance. The visitor is immersed in a sonic field, where the listener experiences its contour largely by sensory dissonance.

We can use sensory dissonance as a tool to help generate atmospheres like Young's Dream House. Sensory dissonance could reveal to us where the various locations are more or less rough in a given space. However, in order to obtain this perspective, we need to extend our calculation to incorporate spatialization factors. These factors would include the locations of each sound source and how the sound occupies and traverses a given space. Once we incorporate such factors into a sensory dissonance model, we have the potential to design immersive sonic environments like Dream House.

In developing a spatialization method, we begin by utlizing the sensory dissonance calculation from Hutchinson & Knopoff as our foundation. We then build on this foundation by accounting for multiple sound sources emanating from multiple locations. When only one sound source is considered outside of space or time, there is only one spectrum that results with a unique level of sensory dissonance. However, when multiple sound sources exist, at each point in the space there is a unique sound spectrum present. Each spectrum, with its unique pairings of frequencies and corresponding amplitudes yields a unique level of sensory dissonance. Because of this, we can compute a unique value of sensory dissonance at

any point in a given space. As a result, we will produce a dissonance field, where there will be different levels of dissonance dispersed throughout the space.

To accomplish this, we need to consider the proximity of a listener with relation to sound sources. Proximity factors include the inverse-square law, atmospheric absorption, and phase. In addition to this, psychoacoustic factors will be considered to more accurately represent a listener's perception of sound. These factors include masking, equal-loudness contours, and the critical bandwidth. Each of these factors, their impact on sensory dissonance, and their incorporation into the model will be detailed below.

C. Inverse-Square Law

The first factor our model accounts for is the sound’s decrease in energy per unit area as a result of the distance it travels. For this, the inverse-square law is applied to adjust loudness levels in the spectrum of each sound source in the space.

As the sound travels radially from a point source in a free field, its energy is dispersed in a spherical pattern. The inverse-square law is an idealization because it assumes that sound propagates equally in all directions. In reality, there are reflective surfaces and structures that, depending on how the sound encounters such objects, have additive and subtractive effects to sound intensity. Nevertheless, our model assumes an

anechoic environment, so a direct application of the inverse-square law is applied.

$$I_2 = I_1 \cdot \left(\frac{r_1}{r_2} \right)^2 \tag{3}$$

where I_1 and I_2 are the sound source intensities and r_1 and r_2 are the sound source distances.

D. Atmospheric Absorption

After adjusting the loudness level in the spectrum of each sound source for the inverse-square law, we make further adjustments for the effects of atmospheric absorption. Essentially, the atmosphere acts as a low-pass filter, since high frequencies become more dissipated than low ones as the sound travels through the air. In order to quantify this effect, ISO standard 9613-1: 1993 was used. This ISO standard gives an analytical method for calculating the attenuation of sound pressure given certain atmospheric conditions. The main inputs required for atmospheric conditions are temperature in degrees Kelvin, atmospheric pressure in kilopascals, and the percentage of relative humidity. The method works for pure-tone sounds ranging from 50 Hz to 10 kHz, with temperatures between -20C and 50C, relative humidity 10% to 100%, and the pressure of air equal to 101.325 kPa.

Because our model assumes an anechoic setting, the effects of atmospheric absorption apply, since like the inverse-square law, reflective

surfaces nullify its effects indoors. Our model also will assume atmospheric conditions with a temperature of 20 degrees Celsius, relative humidity of 50%, and an ambient atmospheric pressure of 101.325 kilopascals. Given these assumptions, we can directly input the frequencies present in a given sound source's spectrum and the distance from that source. What results is the attenuated spectrum of our sound source after undergoing effects of atmospheric absorption.

E. Phase

We must also consider the phase differences in the sounds emanating from various source locations. If the sound sources are at different locations, then the frequency is out of phase, and this must be accounted for when combining amplitudes for our dissonance calculation.

In prior works utilizing the sensory dissonance model of Plomp & Levelt, it has been assumed that all partials of a spectrum are in phase. Thus, when computing the dissonance between two complex tones, it requires only simple arithmetic to combine the amplitudes of two coinciding partials. Because our model is considering spatialization, we can no longer make the assumption of a zero phase spectrum.

Our model does make the assumption that all partials emanating from the same sound source have a relative phase shift of zero. However, with multiple sound sources, since each sound source traverses a unique distance

to reach the listener's location, we must consider the phase perceived by the listener at that point. For most cases, our approach holds because phase only impacts the combination of amplitudes when the difference in frequencies is extremely small. Further, in our case, we do not consider the time domain and its effects of phase on very small differences in frequency. Thus, for our model, we only consider the effects of phase when combining partials of the same frequency.

When combining the amplitudes of two equal frequencies, we need to know the relative phase between two partials before the combined amplitude can be calculated. First, calculate the distance between each sound source and the listener. Given this information and the frequency, we can calculate the phase shift present in each sinusoid. Then, simply subtract the phase shifts present in each sinusoid to get the relative phase between the sinusoids. Finally, knowing the relative phase between the partials, the formula below is utilized to determine the combined amplitude of the partials.

$$A_{combined} = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos(\phi)} \tag{4}$$

where A_1 and A_2 are the amplitudes for two partials with a given frequency, and ϕ is the relative phase between the two frequencies.

F. Auditory Masking

After accounting for proximity factors of spatialization, the next step is to adjust loudness levels for psychoacoustic properties of the listener. The first factor accounted for in this regard is auditory masking.

There are essentially two types of auditory masking, simultaneous masking and temporal masking. Simultaneous masking occurs when both sounds are present at the same time. In addition to simultaneous masking, temporal masking occurs when the masking effect extends outside the period when the masker is present. This type of masking can occur prior to and after the presence of the masker.

Auditory masking is very important to the calculation of sensory dissonance. Any given spectrum could have loud partials that drown out the sound of softer ones. If a given partial is masked, and thus not perceptible to the listener, then we assume it cannot contribute dissonance to the spectrum. Without the consideration of masking, our calculations would depict a dissonance level higher than is actually perceived, and the results could easily be skewed.

Our model assumes a continuous emanation of tones, eliminating the need to consider time. Thus, our model accounts only for simultaneous masking. The masking effect is modeled by utilizing a triangular spread function [2]. The spread function is written in terms of the bark scale difference between the maskee and masker frequencies:

$$d_{brk} = brk_{maskee} - brk_{masker} \tag{5}$$

The bark difference is then input into our triangle function and a masking threshold *T* is calculated

$$T = L_M - \left(-27 + 0.37 MAX\left\{L_M - 40,0\right\}\theta\left(d_{brk}\right)\right)\left|d_{brk}\right| \tag{6}$$

where L_M is the maskers sound pressure level and $\theta\left(d_{brk}\right)$ is the step function equal to zero for negative values of d_{brk} and one for positive values. If the sound pressure level of a given partial is less than the masking threshold, as computed by the triangle function above, then that particular partial is considered masked and is eliminated from the dissonance calculation.

G. Equal-Loudness Contours

After applying the spectral adjustments of auditory masking, the sound-pressure level of each partial is converted to sones in order to account for perceived loudness. When calculating sensory dissonance, prior models rarely take into account psychoacoustic effects of perceived loudness when weighting dyad amplitudes within a spectrum. This approach can lead to inaccurate results because there are drastic differences between a given frequency's sound pressure level and how its loudness is perceived. Thus, when weighting together the dissonance of dyads in a spectrum, our model follows the approach of Clarence Barlow by accounting for perceived loudness via representing amplitude loudness in sones rather than decibels [1]. This is accomplished by utilizing equal-loudness contours.

The equal-loudness contours used in our model are from the current international standard ISO226:2003 [19]. Given a frequency and its sound pressure level, our model uses the equal-loudness contours to convert sound-pressure level to phons. The phons are then converted to sones, which is a linearized unit of measurement for perceived loudness. The sones are then used when weighting together the dissonance of dyads in a spectrum. Using sones rather than sound-pressure level is a more accurate depiction of how the listener perceives partials in the spectrum. The sone based weighting reflects which partials are perceptually more prominent and in turn contribute the most to the sensory dissonance of a spectrum.

Converting decibel levels to sones marks the final adjustment required to calculate the sensory dissonance of a spectrum with consideration for the spatialization of sound sources. Thus, after completing the conversion from decibels to sones, we calculate the sensory dissonance of the spectrum utilizing the modified Hutchinson & Knopoff approach explained above.

III. Sonic Applications of the Spatial Calculation

A. Creating and Visualizing a Dissonance Field

Upon implementing all physical and psychoacoustic impacts into our spatialized dissonance model, we are able to produce a dissonance field. The dissonance field gives us a “topographical” representation of where different levels of dissonance occur in a given space. This is a very powerful result, as

it gives us a vivid perspective on how sensory dissonance can occupy a space in the presence of multiple sound sources.

To construct the field, we first devise a spectrum and three-dimensional location for each sound source. With the sources in place, we then calculate the sensory dissonance at an equally distributed grid of locations in the space. In addition, we make the assumption that the emission and reception of all sounds are omnidirectional. With these assumptions, we can then calculate and visualize the field via the technique of isosurfacing. This technique allows us to scan the dissonance field, revealing the contours and concentrations of dissonance throughout the space.

Following suit with the modeling above, we can construct an example of a dissonance field. To begin, we construct four tones consisting of band-limited saw tooth waves. These tones are placed in a virtual space of 40 cubic meters. Of the four tones constructed, the first tone has a fundamental frequency of 440 Hz. The remaining tones were constructed on top of this as pitches lying in a 12-tone equal tempered major scale. Table 6 below displays the tones constructed and their positions in the space.

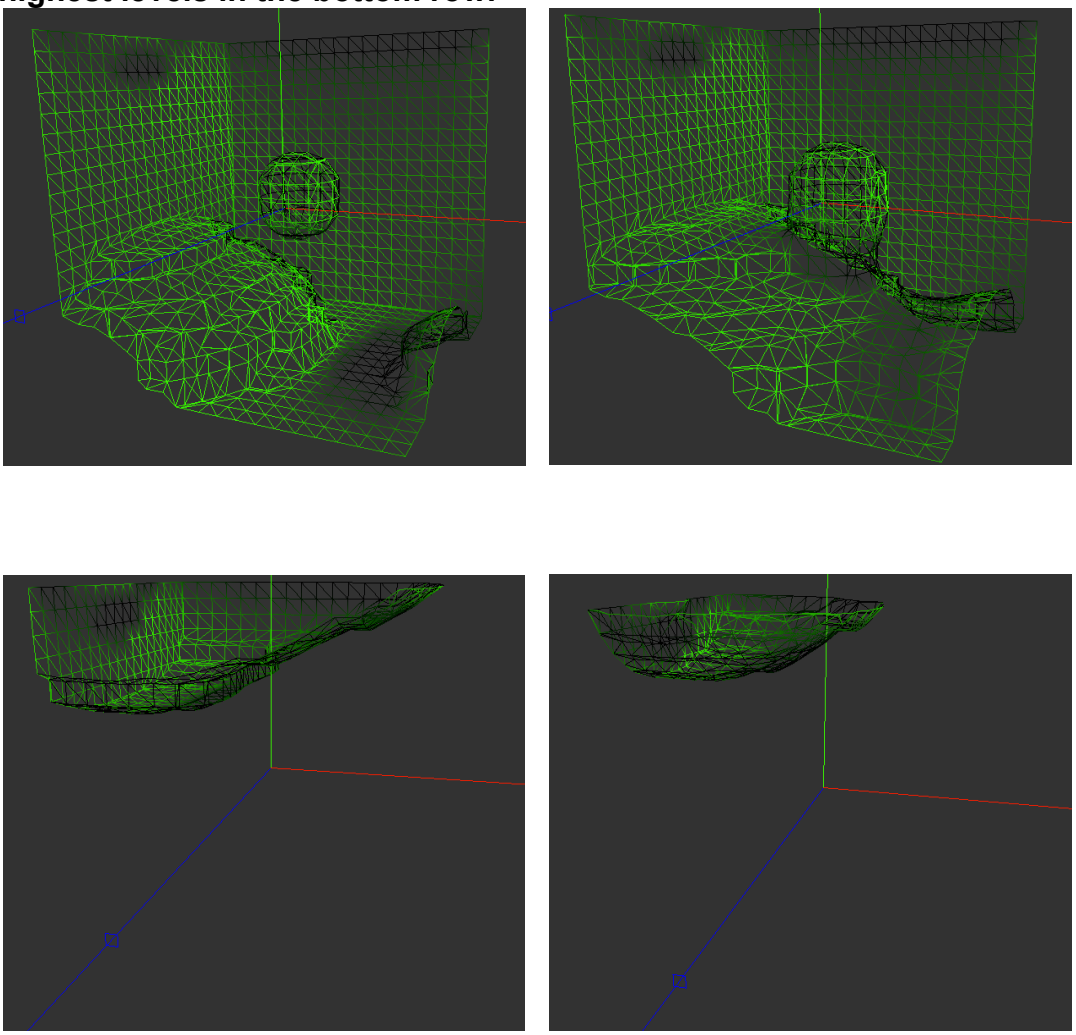
Figure 1. Notes constituting the dissonance field

Fundamental Frequency (Hz)	**Scale Degree**	**Source Location (x, y, z)**
440	Tonic	(8, 8, 8)
493	Major 2nd	(0, 16, 8)
554	Major 3rd	(16, 0, 8)
660	Perfect 5th	(0, 0, 8)

The positions of the tones were selected based on their musical implications. The fundamental of 440 Hz was placed in the center of the space because of its foundational relationship as tonic to the other tones. The third and fifth were placed on the floor because they form a major triad with the fundamental of 440 Hz. Placing them here allows for the illumination of the dissonance relationship in the triad. The second scale degree was placed at the ceiling. As these are the most dissonant tones in the scale (particularly the second), we expect this portion of the room to be more dissonant.

With the tones constructed and positioned, we calculated the sensory dissonance throughout the space at increments of 2.5 meters in all directions. Thus, we generated a 16 cubed matrix housing a total number of 4,096 measurements of dissonance. The images below in figure 4 display our results.

Figure 2. A dissonance field in the virtual space as represented by isosurfacing. Lower levels of dissonance are pictured in the top row, the highest levels in the bottom row.



The images clearly display the topography of the dissonance formed by the sound sources and their placement in the space. The images display snapshots of the different levels of dissonance present ranging from the lowest levels (upper left) to the highest levels (lower right). This

representation gives us a unique insight into the relationships between the tones. It is not surprising that the lowest levels of dissonance are experienced about the placement of the fundamental and the fifth interval (upper left image). Next to this, as the dissonance increases, the topographical surface reveals the presence of the major third interval, and we have a clear visual sense about where the sensation of the common triad is perceived in the space. As the dissonance levels increase further, the topographical surfaces move towards the upper region of the space. It is in this region where the major 2nd interval was placed. As this forms the most dissonant interval against the root tone of 440 Hz, it is clear that this area of the space would have the most sonic roughness.

B. Immersive Environments and Sonic Sculpture

The construction of a dissonance field is our seminal result in modeling the spatialization of sensory dissonance. The field provides a unique perspective on how different sound sources relate to each other and how they are experienced in a space. Exploring the contours of different sonic arrangements in a space can be not only of practical use, but it also yields enormous artistic potential.

Recalling Lamonte Young's *Dream House*, the calculation of a dissonance field allows us to achieve a similar result. We can design immersive sonic environments yielding dissonance contours lush with sonic

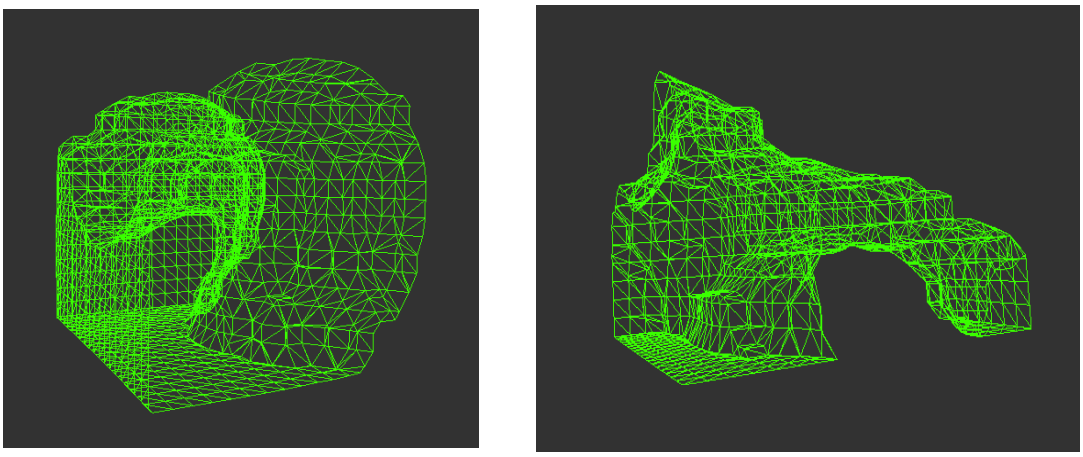
sensations that a visitor can explore. However, as opposed to Dreamhouse, we have the added element of visualization, allowing us to more vividly design the sound space and visitor experience.

In addition, considering the purely physical nature of sound as the vibration of air, we are essentially creating sonic sculptures. We are using sound to position the vibration of air in highly specific ways. With this idea, the physicality of the sound itself is experienced as the artistic focus, rather than the sound having secondary significance as a metaphorical representation. This approach is analogous to the work of James Turrell, whose work involves creating immersive environments and sculptures utilizing light. Turrell creates visual art by flooding spaces or sculpting objects with light. In the environments he constructs, visitors are able to experience the purity of light's affect. In addition, Turrell "sculpts" objects that appear concretely physical in nature, but in actuality are comprised entirely of light. With his approach, it is not the illumination of a particular object that is the focus, but the light itself.

Utilizing our sensory dissonace spatialization model, we were able to construct the sonic sculptures displayed in Figure 6 below, *Curl* and *Arch*. *Curl* is a sonic sculpture based on a justly tuned major triad with fundamental frequency of 100 Hz. The root of the triad is placed in the lower left of the space, while the third and fifth of the chord emanate from sound sources located above and to each side. The overall effect of the sonority is that the dissonance closes in on the fundamental in the curl like shape displayed.

Arch was constructed with six sound sources, where each sound source was placed in the center of one of the six sides constituting the border of the space. Each sound source emanates a sine tone, and each tone is separated in frequency by 0.25 barks (the point of maximum roughness, i. e. sensory dissonance, in a given critical band). The setup results in the arch like dissonance field caused by the convergence of the sounding tones.

Figure 3. Two sonic sculptures: Curl (left) and Arch (right)



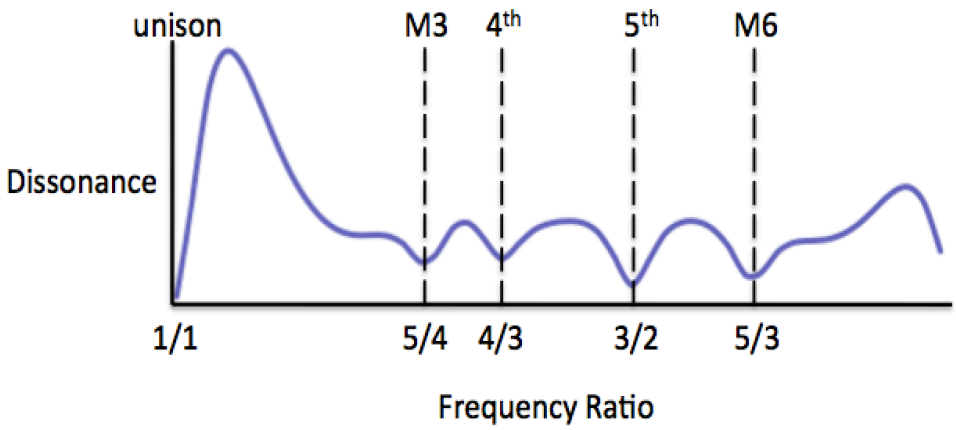
IV. Harmonic Implications of Sensory Dissonance

A. Background

Prior to electronics, musical sound production was limited to the physical properties of acoustic instruments. The vast majority of such instruments generate complex tones consisting of integer related partials that form the harmonic series. When we combine complex tones from these

instruments some tone combinations are smooth, while others are rough. This roughness/smoothness in the resulting combination of sonorities is a direct result of their spectral makeup. The roughness in the sound is a function of the frequency distance between each complex tone. Plotting this relationship produces a dissonance curve.

Figure 4. A dissonance curve and corresponding intervals



The local minima present in the figure above show a strong correlation between traditional classifications of consonant vs. dissonant intervals and the sensory dissonance (roughness) between complex tones. For example, the interval of the fifth, considered one of the most consonant intervals, is among the lowest of the minima in the dissonance curve. The interval of the third, still considered very consonant but less so than the fifth, is situated accordingly in the curve.

The dissonance curve displayed above has been the most common

one coinciding with centuries of music creation. This is because we have been generating sound from acoustic instruments, whose physical properties limit the spectral production to the integer related partials making up the overtone series. This curve is fundamental to the music theory of scales and harmony, which in turn has influenced the majority of compositional practices.

B. Harmonic Potential and sinophonme

With the advent of electronic music, we are now free from the physical restrictions of acoustic instruments. There now exist endless possibilities for complex tone generation that are not confined to the traditional sonority of integer related partials and the overtone series. Because of this, it is now conceivable to engineer a sonic spectrum that produces a dissonance curve far different than the figure displayed above. Such a curve would imply consonance and dissonance relationships between tones that are quite different from traditional teachings. For example, a fifth may actually be dissonant, or a tritone the most consonant interval.

If we are able to craft unique sonic spectra that yield new and unique hierarchies of harmony and scale, what does this mean for traditional harmonic practices (chord progressions, rules of counterpoint)? Will we reinforce or destroy our long established traditional practices of harmony? How might we begin to explore such impacts?

One approach is to look at historic origins of musical style as a

guideline. When defining something new, it is typical that a certain level of mastery of the most basic features is attained before further developments are explored yielding greater complexity. For example, the earliest medieval music, being relatively primitive and undeveloped, focuses on the most salient qualities of musical scales and intervals. The earliest treatises, such as the *Musica Enchiriadis* and that of *Anonymous IV*, define a grammar for the different forms of consonant and dissonant intervals and their compositional implementation.

With the construction of unique dissonance curves, there is a similar aim. Each curve yields a redefinition of the hierarchy of consonant and dissonant intervals. Thus, a basic compositional implementation of such new hierarchies is needed in order to expose a curve's musical potential. The medieval form of organum provides a nice framework to accomplish this, which is demonstrated in the piece *sinophonme*.

The sonic palette of *sinophonme* is derived from a generated complex tone resulting from additive synthesis. The harmonic structure of the piece is then rooted in the theory of developing scales from dissonance curves as presented in William Sethares' *Tuning, Timbre, Spectrum, Scale* [19] and as alluded to above. The theory states that a unique scale can be devised from the unique spectral makeup of a given pitch. To accomplish building a scale, the procedure is as follows:

1. Design the spectral makeup of a complex tone via additive synthesis.
2. Produce a dissonance curve based on the spectral content of the designed complex tone.
3. Find the local minima in the resulting dissonance curve. These locations will serve as frequency ratios for scale tones.

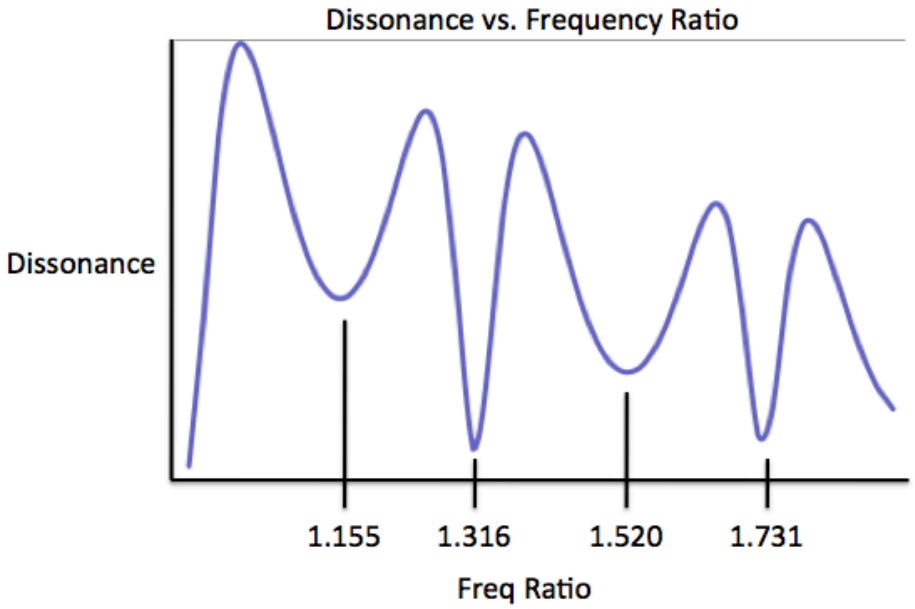
For *sinophonme*, the following spectral makeup constitutes a given tone:

Figure 5. Spectral makeup of a complex tone in *sinophonme*

Spectral Makeup of Each Tone					
Partial	**1**	**2**	**3**	**4**	**5**
Freq (Hz)	420	556	734	967	1265
Cents	0	486	966	1,444	1,909
Amplitude	1.00	0.50	0.33	0.25	0.20

This spectrum then yields the dissonance curve with local minimums at ratios in the figure displayed below.

Figure 6. The dissonance curve resulting from complex tones used in *sinophonme*



The scale of the piece is then made to consist of five tones, where each tone is separated by a whole step plus an extra quarter or eighth step. The scale makeup along with cent information is displayed below:

Figure 7. Scale tone makeup in *sinophonme*

Scale Makeup in sinophonme					
Scale Degree	1	2	3	4	5
FundFreq(Hz)	420	485	553	638	727
Ratio	1.000	1.155	1.316	1.520	1.731
Cents	0	250	475	725	950
Cents Chg	0	250	225	250	225

This scale was replicated over a span of three octaves, yielding a total of fifteen pitches available for compositional use:

Figure 8. Fundamental frequencies of pitches used in *sinophonme*

Pitch Frequencies (Hz) in Each Register					
High Register	420	485	553	638	727
Mid Register	210	243	276	319	364
Low Regsiter	105	121	138	160	182

With *sinophonme* we are defining and exploring a new grammar, and thus, the compositional aim of the piece is to explore its sonic context. This was achieved by adopting the organum style. The lowest pitch of the piece, which is droned throughout, acts as the fundamental from which the dissonance curve was derived. The upper voices then move in a somewhat free manner exploring the dissonances produced among them and against the drone. Thus, the composition is an exploration of the consonance and dissonance present in our dissonance curve.

Of the endless amount of possibilities available for timbral makeup of a given tone and resulting scale construction, this particular arrangement was selected because of the balance and contrast present in the dissonance curve. The curve shows that all the odd numbered tones in the scale have the lowest sensory dissonance, where all the even tones sound relatively more rough. Intervallic pairings of odd numbered tones sound akin to perfect intervals in the standard Western scale, while the 2nd and 4th degrees paired

together still sound very consonant, but not quite as smooth. In addition, the scale is well balanced in that scale tones are separated by approximately the same amount. This feature can be easily contrasted when examining other dissonance curves, as often local minima are more irregularly dispersed.

V. Controlling Sonic Roughness and *Sensations of Tone*

The invitation to create an endless variety of scales and harmonic hierarchies from a uniquely crafted sonority and dissonance curve is intriguing. Yet, it can be equally stifling, as the composer can be left confounded by too much choice. To quote Igor Stravinsky, "Whatever diminishes constraint diminishes strength. The more constraints one imposes, the more one frees one's self of the chains that shackle the spirit."

Thus, rather than try to re-define a unique harmonic grammar for a particular sonority and dissonance curve, perhaps sensory dissonance can be put to a different utility. Perhaps the measurement of sonic roughness is not a means to an end, but an end in itself. With this notion, we can devise a method that allows us to explore the intrinsic qualities of sensory dissonance, that is sonic roughness, and we can allow the method to unfold as a composition.

The piece *Sensations of Tone* accomplishes this via an algorithm that synthesizes complex tones with varying degrees of sensory dissonance. Due to the non-linearity present in determining sensory dissonance of complex

tones, a constraint-based algorithm is used to perform additive synthesis and generate a tone within certain roughness bounds. The algorithm requires the following inputs: target fundamental frequency, number of partials to comprise the complex tone, and the target range of sensory dissonance. Given these inputs, the algorithm generates a complex tone with a desired level of roughness as follows:

1. Given a fundamental frequency, randomly generate a frequency and amplitude spectrum above the fundamental, such that each partial is within 1.4 barks of the fundamental.
2. Given the spectrum of the complex tone generated in step 1, calculate the sensory dissonance of this spectrum and compare it to our target sensory dissonance.
3. If the sensory dissonance of the spectrum falls within the range of our target, return the generated spectrum. If not, make adjustments to the spectrum and repeat the steps above until the complex tone falls within the desired roughness bounds.

The crucial step in generating a tone with desired roughness is adjusting its spectral content when its roughness falls outside the designated boundary. To accomplish this, we can look more deeply into the Hutchinson & Knopoff dissonance equation to assist us in adjusting the spectral content that would suit our roughness goal.

Recall the Hutchinson & Knopoff equation (1) above. Using this equation, we can determine each sinusoid's contribution of dissonance to the spectrum by calculating partial dissonances. The partial dissonance is the aggregate of amplitude weighted sensory dissonances between a given partial and all other partials in a complex spectrum. It is mathematically defined as follows:

$$PD = \sum_{i=1}^{N} A_0 A_i g_{0i} \tag{7}$$

where N is the number of partials, A_i represents the amplitude of a partial, and g_{0i} is the sensory dissonance of a given dyad based on the critical bandwidth between their frequencies.

The partial dissonance metric can be directly extracted from the Hutchinson & Knopoff equation by adding the rows or columns of a given partial in the spectrum. The partial dissonances of the spectrum tell us which sinusoid contributes the most/least dissonance to the entire spectrum. Knowing this, we can exercise control over the sonic roughness of a spectrum by manipulating the sinusoids leading us away from our target.

In step 3 above, if we determine the spectral roughness to be outside of our target, we can now meaningfully adjust our spectrum. First, using partial dissonance, determine which sinusoid causes the most deviance from our target dissonance. Then replace this partial with a newly generated frequency and amplitude as described in step 1. Next, we repeat steps 2

onward until ultimately we have generated a spectrum with a target level of roughness.

The piece *Sensations of Tone* utilizes the roughness generation procedure described above. The piece aims to immerse the listener into various sonic spectra, as it explores the intrinsic qualities of sensory dissonance via the roughness generated in the sound. This goal has its influence lying in the work of James Turrell's light sculptures. Turrell's light installations are highly immersive, as the user is engulfed in different illuminated environments. Analogously, *Sensations of Tone* is an attempt to accomplish a similar effect in sound.

This concept is achieved via utilization of the roughness generation algorithm, dissonance curves, and spatialization of the generated complex spectra. With respect to sound generation, initially three complex tones are produced, where each is generated from a selected fundamental frequency and desired roughness level. The resulting tones then form a unique dissonance relationship, and this relationship is described by a dissonance curve resulting from their spectra. As with *sinophonme*, we then explore various transposition ratios among the tones by selecting those that correspond to local minima in their dissonance curve. This procedure of generating spectra based on roughness, and then selecting tones from dissonance curves allows us to develop and explore musical material by primarily focusing on the desired level of roughness in the sound.

The immersive quality of the piece is ultimately achieved through the spatialization of the sound. The piece was set in the Allosphere at the University of California Santa Barbara, which is comprised of a 54.1 surround speaker system. The speakers are distributed in three rings: an upper ring of 12 speakers at 30 degrees in elevation, a middle ring of 30 speakers at 0 degrees, and a lower ring of 12 speakers at -30 degrees. Given the broad array of speakers, the location of each sound, in terms of elevation and azimuth, is precisely placed via the technique of ambisonics.

Once a complex tone is generated, it is then deconstructed into its sinusoidal components. Upon deconstruction, each sinusoid of the complex tone is individually placed at a specific location in the allosphere. The sinusoids can be positioned such that all are highly focused to one location, or they can be spread throughout the entire sphere, surrounding the listener. This enhances the perceptual experience of each complex tone, allowing the listener to at times experience the spectral roughness from the outside, and at other times engulfed inside the sonic spectra.

To enhance the quality of spectral immersion, the partials are constantly emitted from unique spatial locations and in unique combinations. The listener never hears all tones of the spectrum attack simultaneously. Rather, they are presented with a dynamic cloud of sinusoids constantly appearing and fading away. As they overlap with each other, the spectral quality of roughness or smoothness is then experienced in aggregate.

Sensations of Tone allows us to engineer sonic environments with various degrees of roughness from the ground up. Upon generating complex tones with the roughness algorithm, we can explore their musical relationships via dissonance curves, and ultimately immerse the listener in the sound via the spatialization techniques employed.

VI. Conclusion

The three methods outlined above give us enormous compositional potential for utilizing the concept and calculation of sensory dissonance. We can calculate the sonic roughness at various points in a three-dimensional space, and in doing so essentially shape the sound into sonic sculptures that visitors can explore with their ears rather than eyes. We can explore the musical potential of non-harmonic sounds by using dissonance curves as a guide to formulate new and unique scales and harmonic hierarchy. Finally, we can use our roughness generation approach to explore the intrinsic qualities of sensory dissonance and sonic roughness itself. Using these techniques individually or in ensemble opens the door for new compositional approaches with timbre, harmony, and environment.

References

1. Barlow, Clarence (1980). Bus Journey to Parametron. *Feedback Papers 21-23.* Feedback Studios Cologne.

2. Bosi, M. (2003). *Audio Coding: Basic Principles and Recent Developments.* Paper presented at the HC International Conference.

3. " Damping of Air of High Frequencies." Web. 20 Nov. 2011. <http://www.sengpielaudio.com/calculator-air.htm>.

4. " Formula for calculating the damping of air." Web. 20 Nov. 2011. <http://www.sengpielaudio.com/AirdampingFormula.htm>.

5. Chon H. C. (2008). *Quantifying the Consonance of Complex Tones With Missing Fundamentals*. Thesis submitted to Department of Engineering, Stanford University.

6. Helmholtz, H. von. (1877). *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik.* 1877, 6th ed., Braunschweig: Vieweg, 1913; trans. by A.J. Ellis as *On the sensations of tone as a physiological basis for the* theory of music" (1885). Reprinted New York: Dover, 1954.

7. Huron, D. (1991a). Tonal consonance versus tonal fusion in polyphonic sonorities. *Music Perception,* Vol. 9, No. 2, pp. 135-154.

8. Huron, D. (1993). A derivation of the rules of voice-leading from perceptual principles. *Journal of the Acoustical Society of America* Vol. 93, No. 4, p. S2362.

9. Huron, D. (1994). Interval-class content in equally-tempered pitch-class sets: Common scales exhibit optimum tonal consonance. *Music Perception,* Vol. 11, No. 3, pp. 289-305.

10. Hutchinson, W. & Knopoff, L. (1978). The Acoustic Component of Western Consonance. *Interface*, Vol. 7, No. 1, pp. 1-29.

11. "Inverse-square Law." *Wikipedia, the Free Encyclopedia*. Web. 20 Nov. 2011. <http://en.wikipedia.org/wiki/Inverse-square_law>.

12. Jacobsson, B. & Jerkert, J. (2000). *Consonance of non-harmonic complex tones: Testing the limits of the theory of beats*. Unpublished project report. Department of Speech, Music and Hearing (TMH), Royal Institute of Technology.

13. Kameoka, A. & Kuriyagawa, M. (1969a). Consonance Theory, Part I: Consonace of Dyads. *Journal of the Acoustical Society of America*, Vol. 45, No. 6, pp. 1451-1459.

14. Kameoka, A. & Kuriyagawa, M. (1969b). Consonance Theory, Part II: Consonance of Complex Tones and its Computation Method. *Journal of the Acoustical Society of America,* Vol. 45, No. 6, pp. 1460-1469.

15. Mashinter, K. (1995). *Discrepancies in theories of sensory dissonance arising from the models of Kameoka & Kuriyagawa and Hutchinson & Knopoff*. Bachelor of Applied Mathematics and Bachelor of Music joint thesis, University of Waterloo.

16. MacCallum, J., Einbond, A. (2007) *Real-Time Analysis of Sensory Dissonance* Center for New Music and Audio Technologies (CNMAT), Berkeley, CA.

17. Parncutt, R. (2006). Commentary of Keith Mashinter's "Calculating Sensory Dissonance: Some Discrepancies Arising from the Models of Kameoka & Kuriyagawa, and Hutchinson & Knopoff." *Empirical Musicology Review*. Vol. 1, No. 4, 2006

18. Plomp, R. & Levelt, W.J.M. (1965). Tonal consonance and critical bandwidth. *Journal of the Acoustical Society of America,* Vol. 38, pp. 548-560.

19. Sethares, William A. (2005) *Tuning, Timbre, Sprectrum, Scale*. London: Springer-Verlag.

20. Suzuki, Yoiti. (2003) *Precise and Full-Range Determination of Two-dimensional Equal Loudness Contours*.

21. Tenney, J. (1988). *A History of "Consonance" and "Dissonance."* White Plains, NY: Excelsior, 1988; New York: Gordon and Breach, 1988.

22. Vos, J. (1986). Purity Ratings of Tempered Fifths and Major Thirds. *Music Perception*. Vol. 3, No. 3, pp. 221–258.

Part Two:

A Portfolio of Compositions

I.

Binated Triphasis

for two bass clarinets in Bb, two bassoons, and two horns in F

Binated Triphasis is a piece for sextet consisting of two bass clarinets in Bb, two bassoons, and two horns in F. The piece is a juxtapositional play on the on the titular terms, which is an elusion to the piece's fundamental structure lying in orchestration, form, and concept. Binated, occurring in pairs, refers to the orchestrational pairing of each instrument, and how each section presents a duality between static and active musical material. Triphasis, three phases, most literally derives from the pieces formal structure: static, active, and then extended. In addition, the ensemble consists of three instrumental families, where there is a one-to-one correspondence between the composition's formal sections and instrumental families occupying the sonic foreground: section 1 presents the horns, section 2 the bassoons, and section 3 the bass clarinets. The interplay between the terms is present throughout the piece on local and global levels.

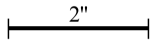
Binated Triphasis

for two bass clarinets, two bassoons, and two horns in f

Brian Hansen
2007

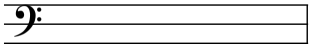
Performance Notes

General Notations

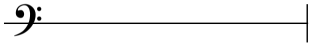


No activity for the specified duration.

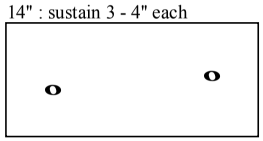
a) one-quarter flat. b) one-quarter sharp.



The three line staff is an indication of register, where the top line corresponds to the upper register, middle line the middle register, and bottom line is the lower register. Pitches notated on these lines should sound in the instruments respective register. Pitches notated above, below, or in between the lines should be played in proximity to the register indicated.



The one line staff indicates that no tone should be produced from the instrument.



Boxed passages are played as follows:

a. Temporal direction is displayed above the box. The duration of the box passage is indicated to the left of the colon. The manner in which the material within the box should be metered is indicated to the right of the colon.

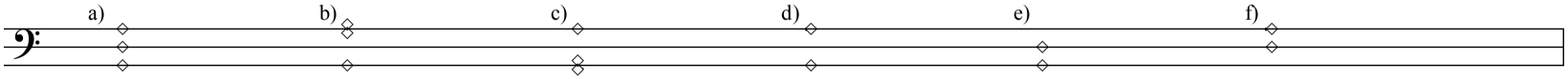
b. Passages within the box are independent of of surrounding material and thus need not be metrically in sync with the surrounding material.

Verticle slashes through noteheads indicates breath only, no picth, should be produced.

An unslashed notehead tied to a slashed notehead indicates that a pitched tone should seemlessly transform into breath only (or vice versa).

Attack with tongue, producing a "tuh" sound and no pitch.

Flutter tongue and tremolo simultaneously.



Multiphonic Notation:
The performer must choose the multiphonics to be produced based on the notated texture, register, and dynamics. These three parameters are notated as follows:

Texture: Thick textured multiphonics are indicated by three pitches as in a, b, and c. Thin textured multiphonics are indicated by two pitches as in d, e, and f.

Register: The register of the tones produced are indicated by the placement of noteheads on the three-line registral staff.

Dynamics: The dynamics of each multiphonic are traditionally indicated in the score (e.g. p, mf, f).

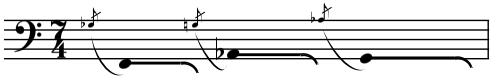
As an example, compare notations for multiphonics a, b, d, and e. Multiphonic "a" should be thick in texture, and the tones produced should be evenly distributed among the registers of the insturement. Multiphonic "b" should be thick in texture with tones sounding in the low and upper registers, but with a greater sonic concentration in the upper register. Multiphonic "d" should be thin textured with tones produced in the lower and upper register, and "e" is also thin but with tones produced in the middle and upper registers.

For further instruction on multiphonic production, the performer should consult the following texts:

1. New Sounds for Woodwinds, Bruno Bartolozzi
2. New Directions for Clarinet, Phillip Rehfeldt.

Clarinet

To accurately produce this gesture, the grace note should be accented and the subsequent landing note should be as quiet as possilbe. Following this, there should be a dynamic swell, where as the swell recedes, the pitch bends downwards. These gestures are spacially notated as explained below.

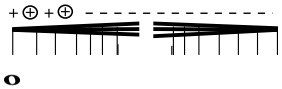


Measures containing this type of gesture are spacially notated. Each gesture's point of attack should be approximated by its position in each measure, and the sustain should be approximated by the length of each gesture's horizontal line. For these measures, time signature does not apply to the metrical distribution of each gesture within the measure; it only indicates the time span over which a series of these gestures should occur.

Horn

Slap tongue.

Key clicks.



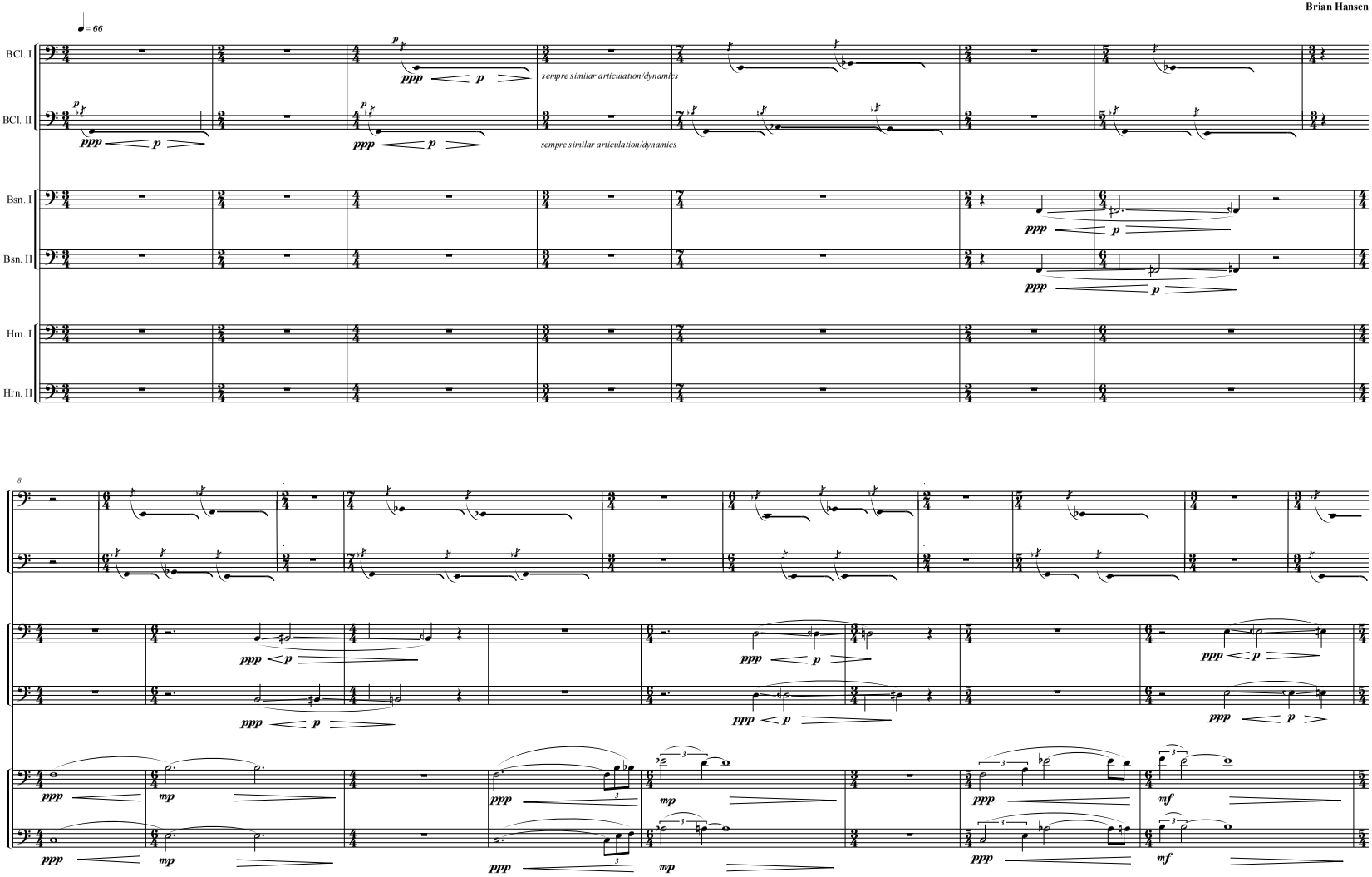
While the pitch is sustianed, the horn should tremolo between fully stopped and half stopped. The stop tremolo should accelerate and decelerate.

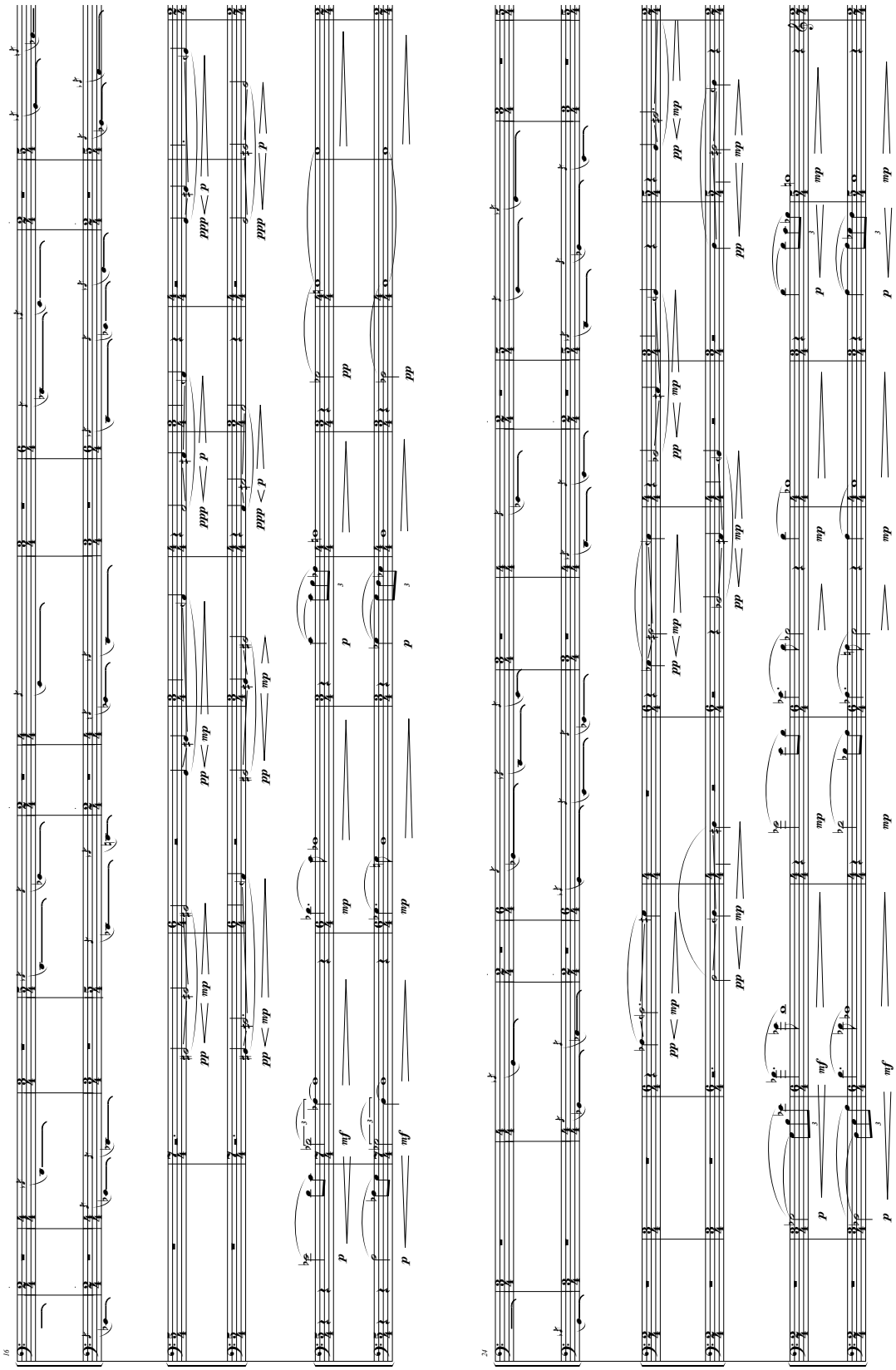
The horn player should produce their absolute lowest possible tone. The pitch produced will most likely be different for each player and sound very unsteady, both of which are desireable.

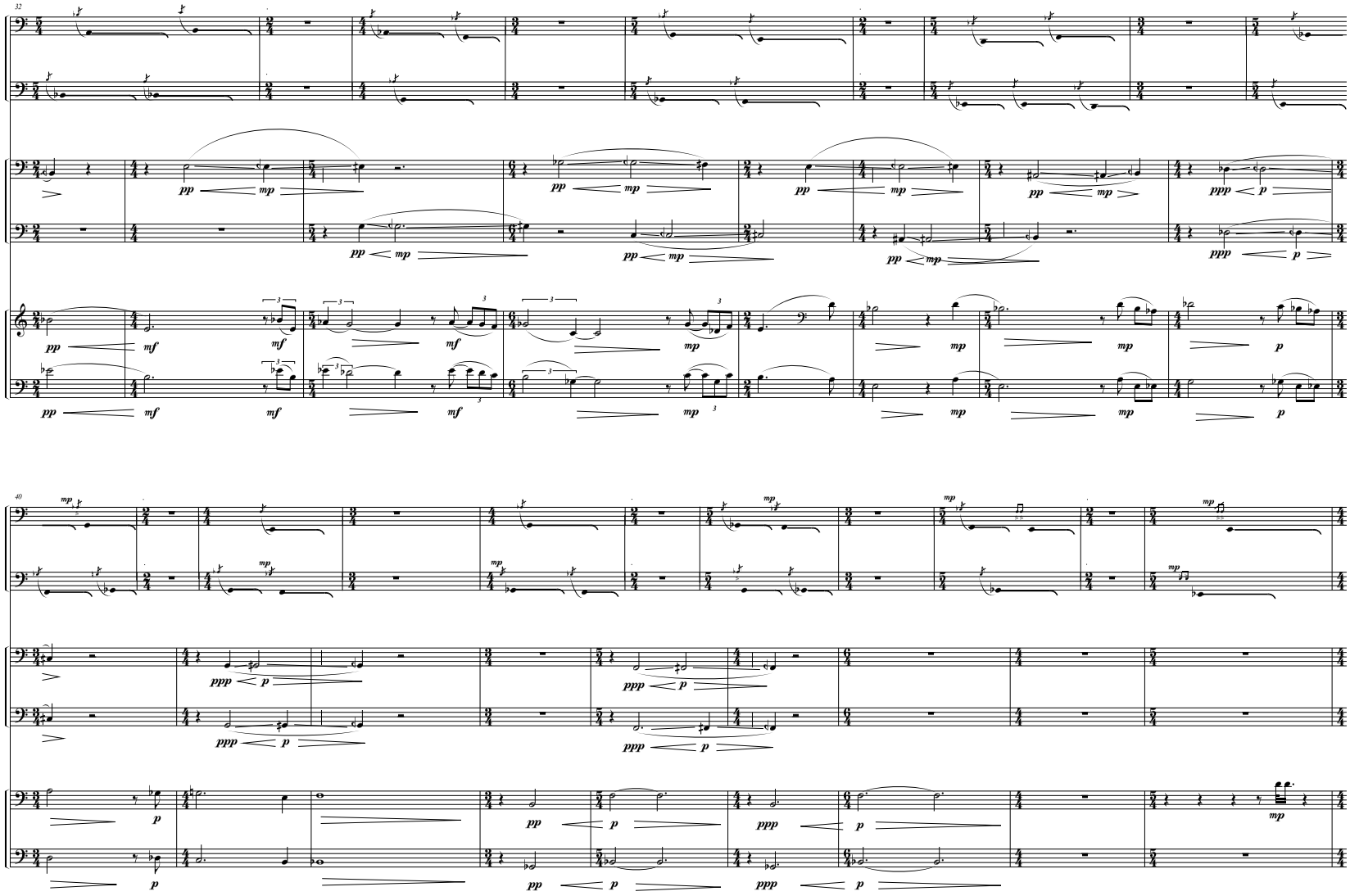
Binated Triphasis

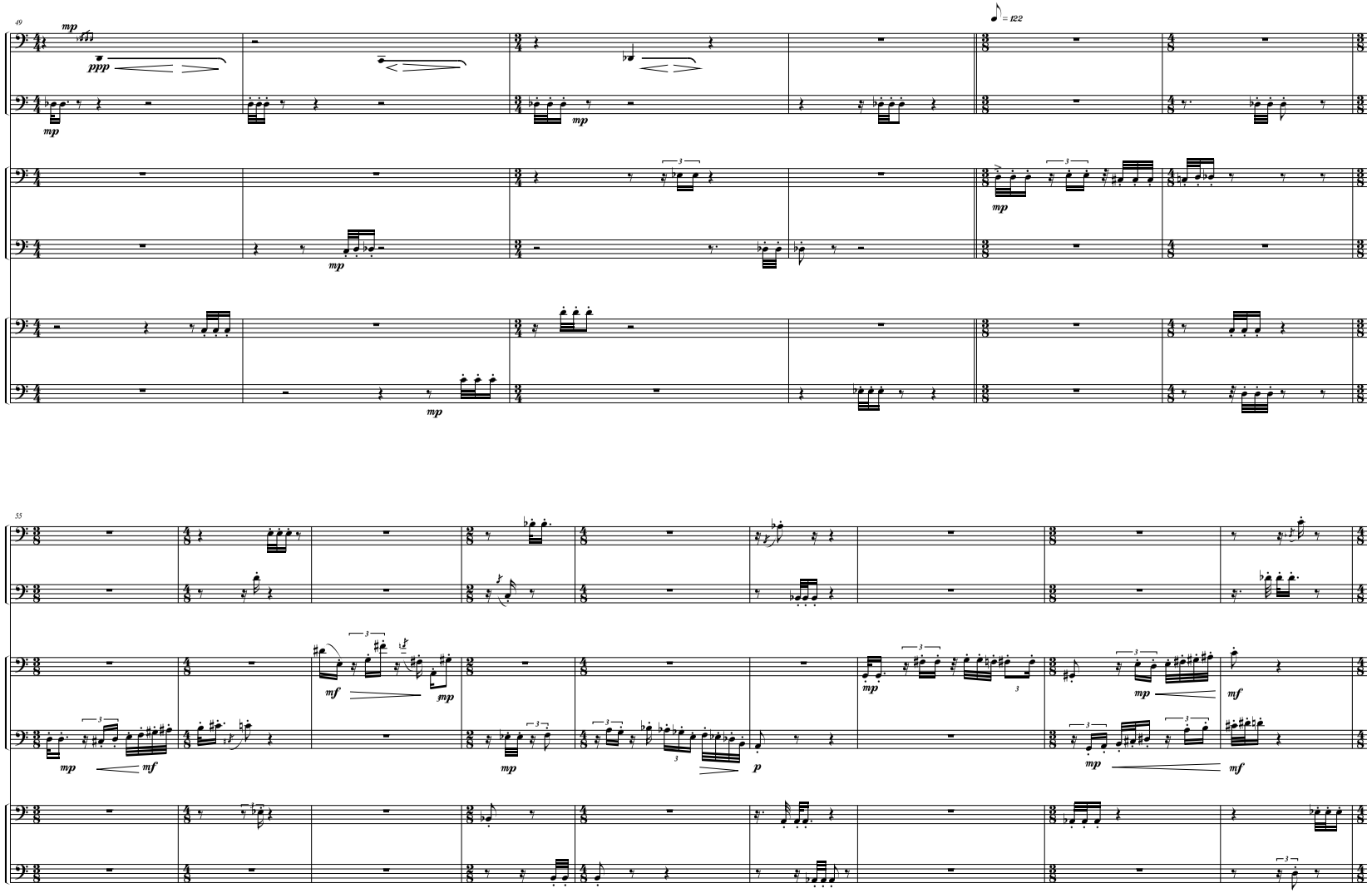
Score in C

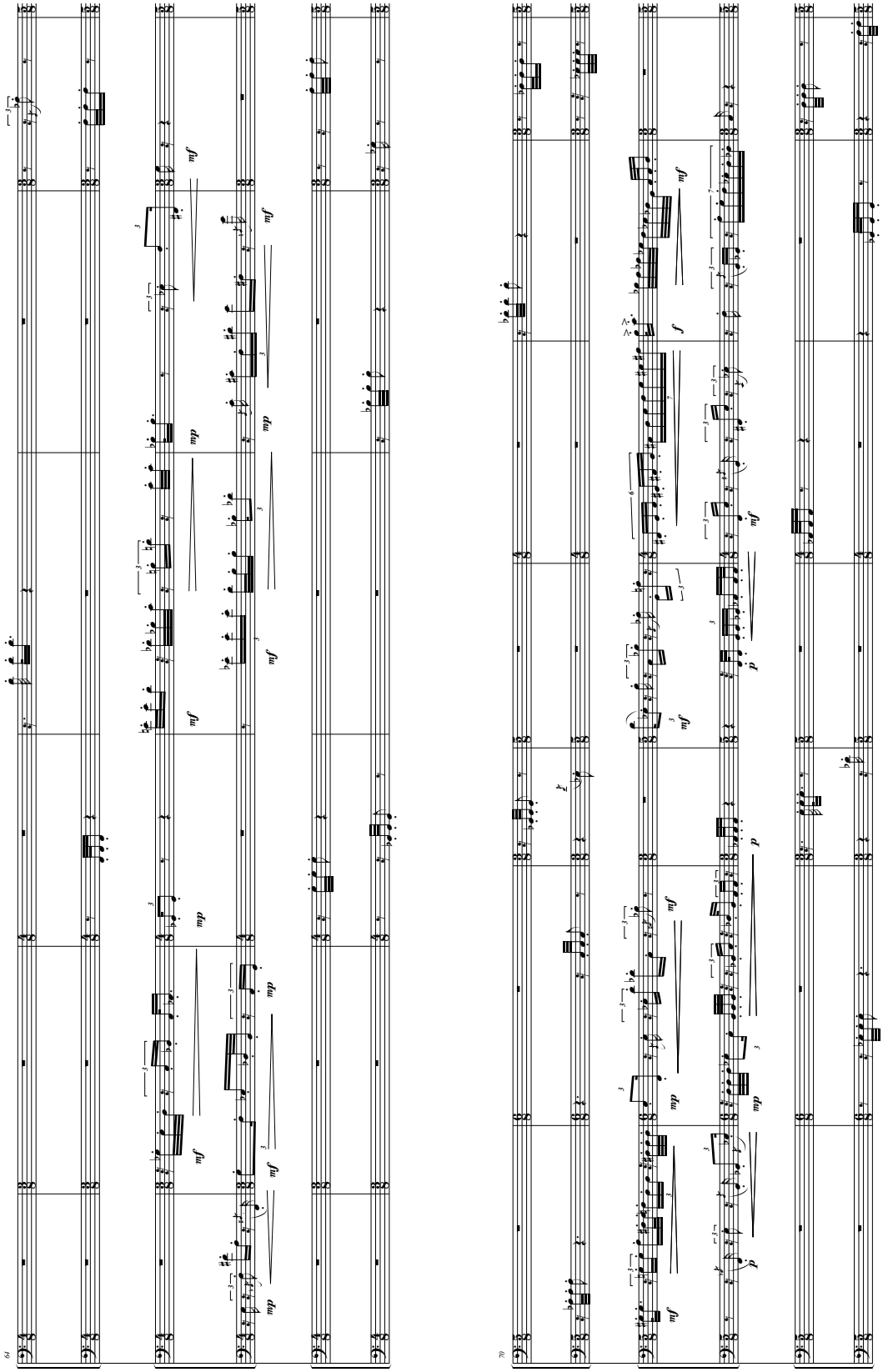
Brian Hansen

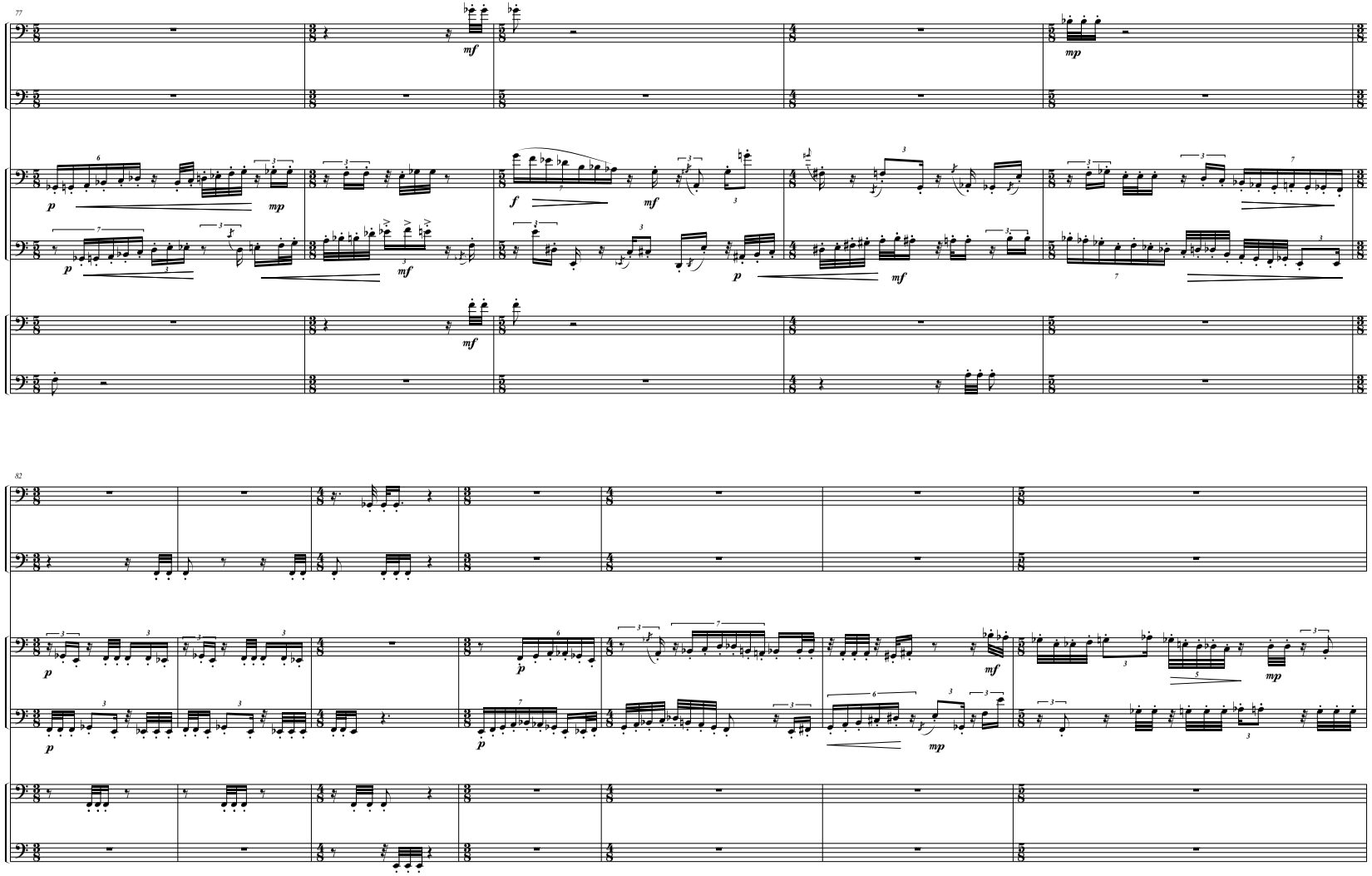


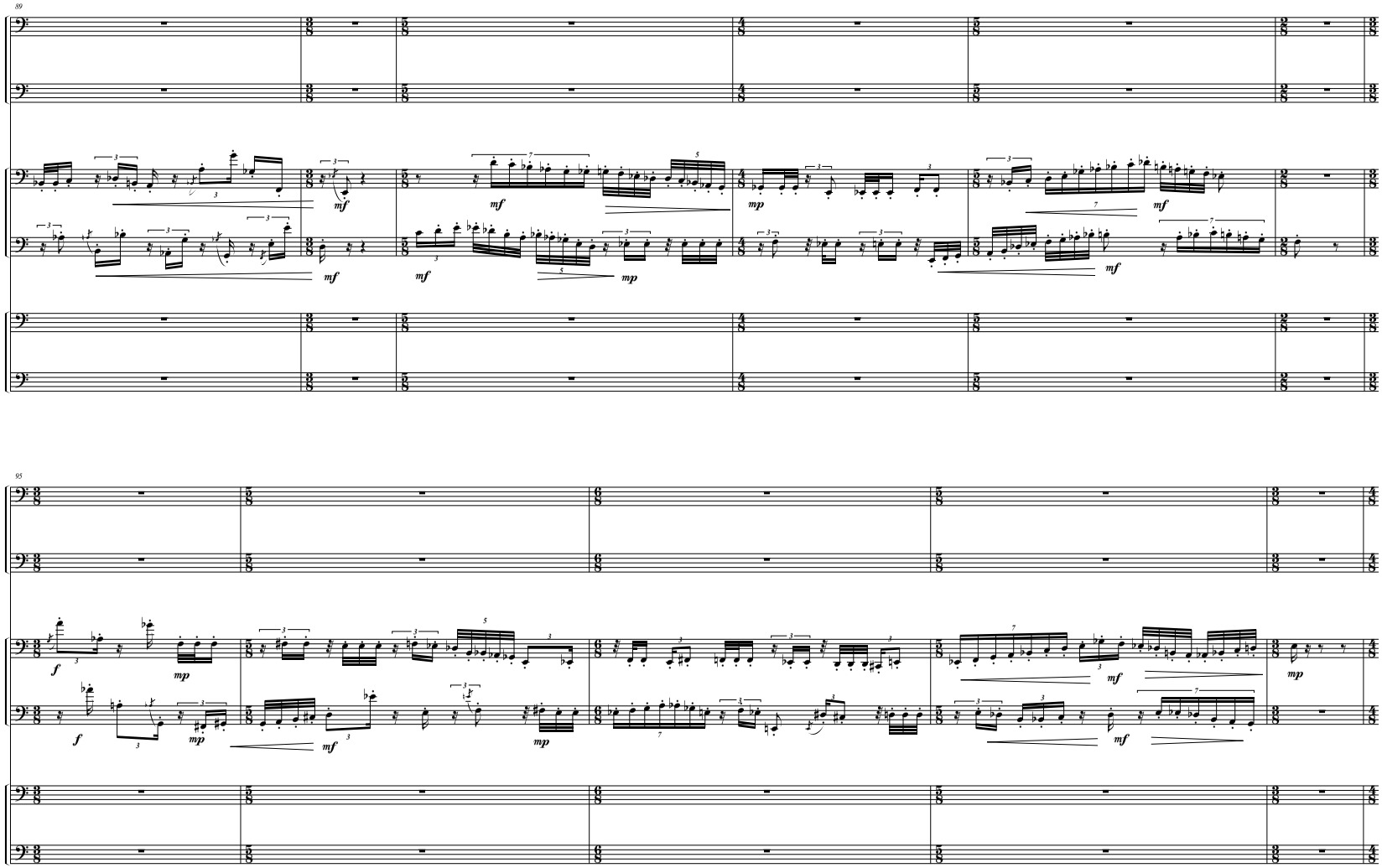

16
24
p
mf
dim
mp
dd
ddd

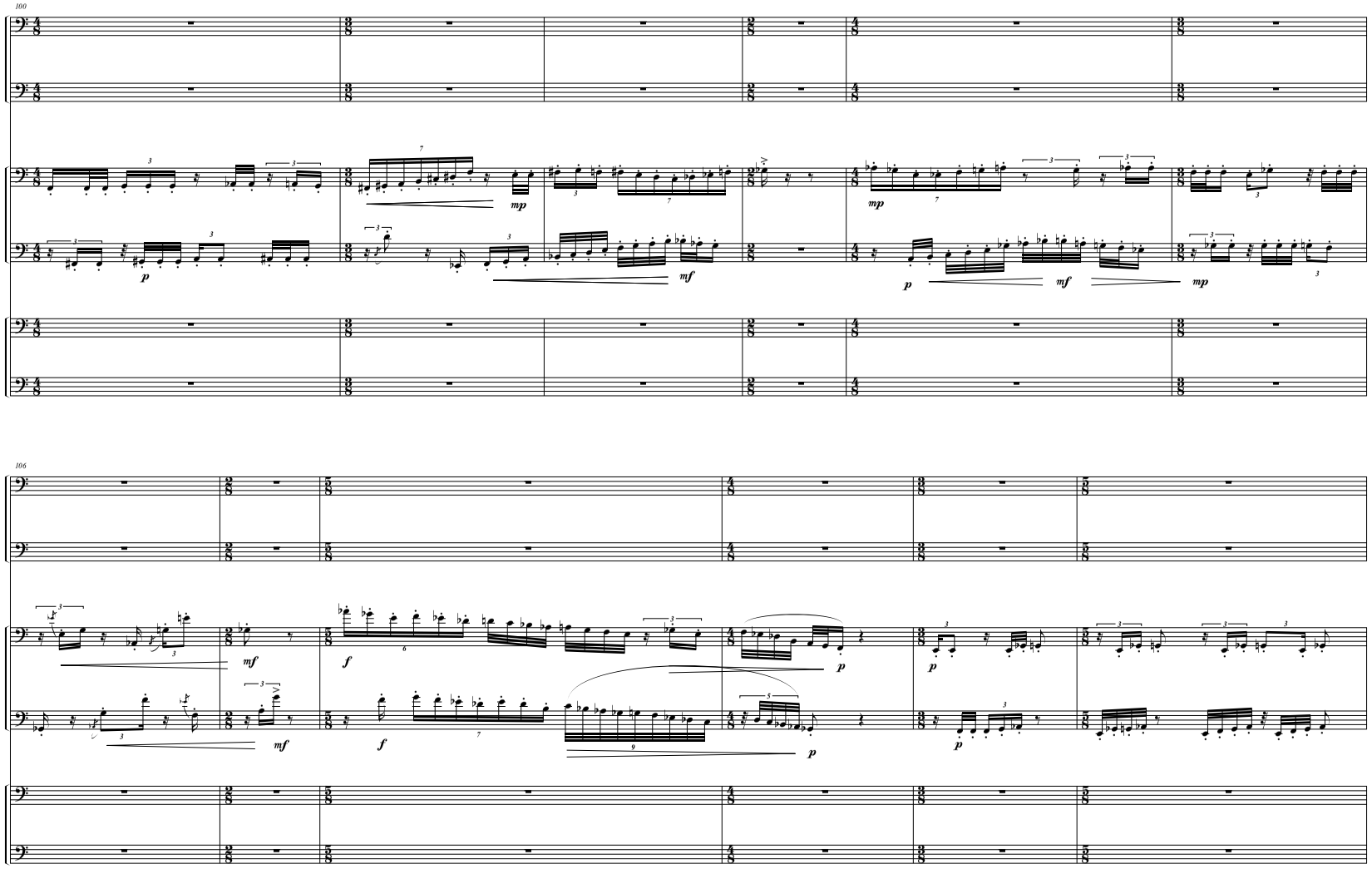

32
pp
mp
ppp
p
mf
40

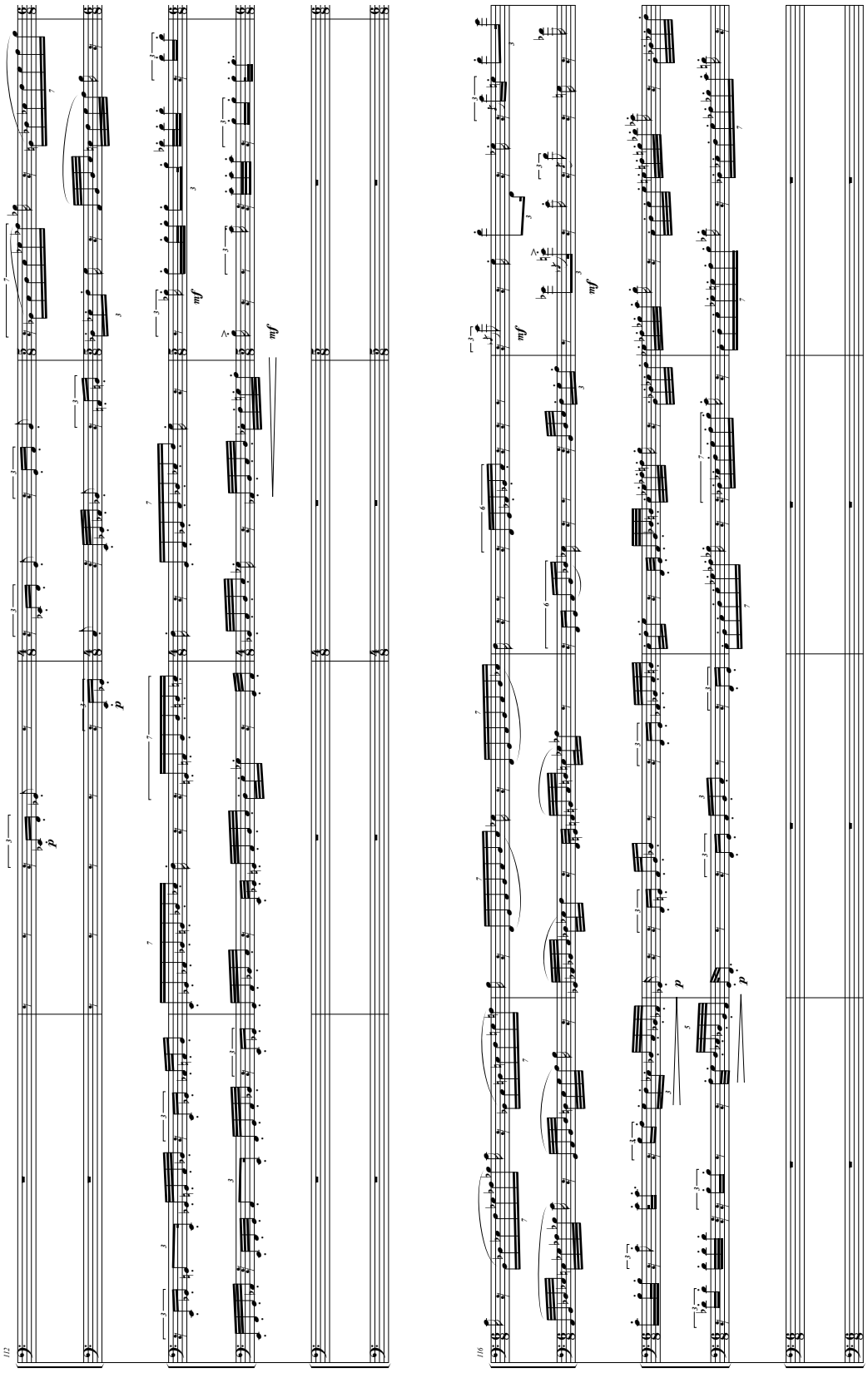

49
mp
ppp
mp
mp
mp
mp
= 122
mp
mp
55
mf
mp
mp
mf
mp
p
mp
mf
mp
mf

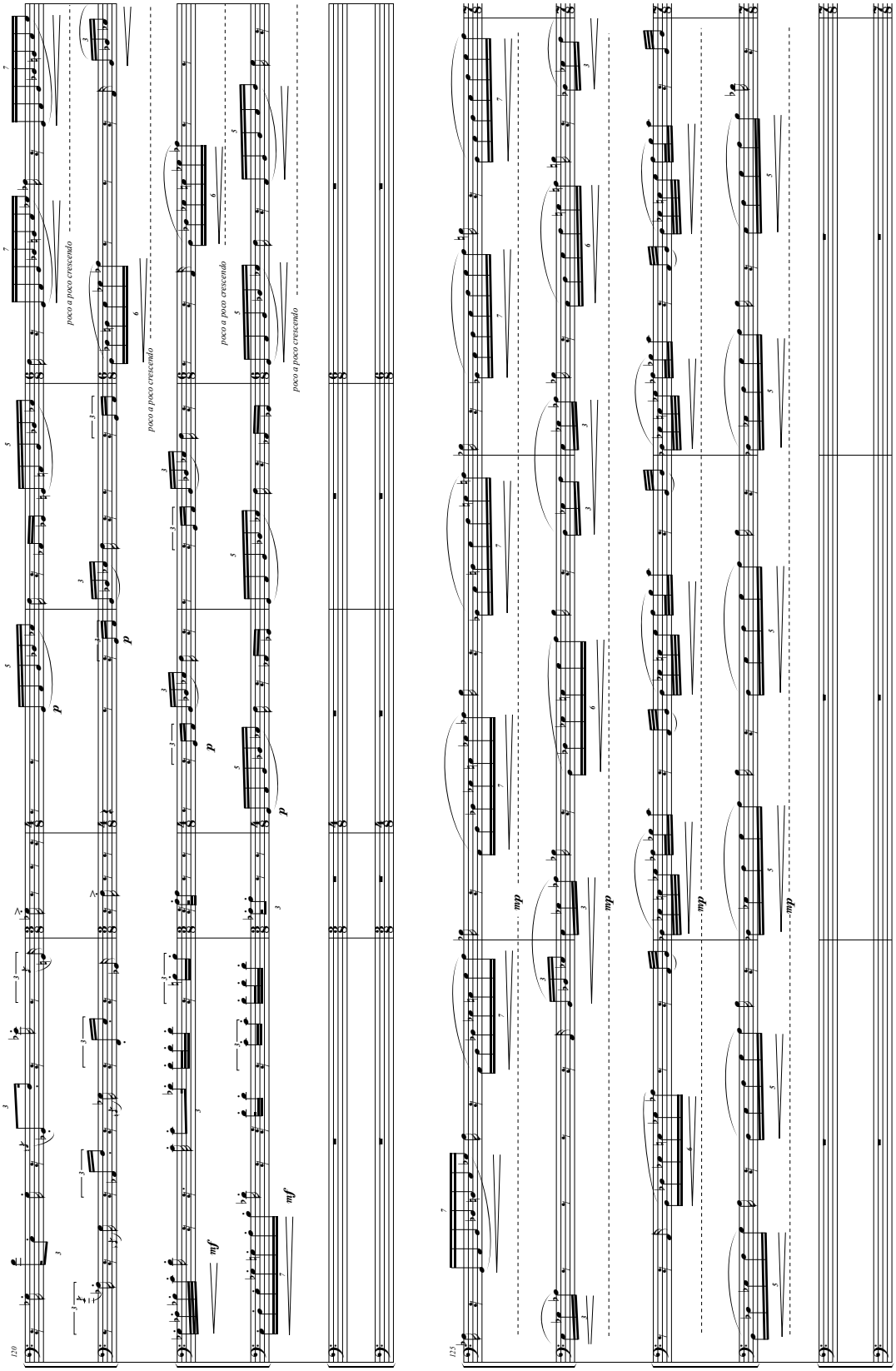

69
mf
fw
dw
fw
mf
fw
dw
dw
fw
fw
dw
70
mf
f
mf
d
fw
d
fw
dw
dw
d
mf


77
mf
mp
p
mp
mf
f
mf
p
mf
mf
82
p
p
p
mf
mp
mp


89
mf
mf
mf
mp
mf
95
f
mp
f
mp
mf
mp
mf
mp


100
p
mp
mf
mp
p
mf
mp
106
mf
f
p
p
mf
f
p
p


112
p
p
mf
mf
116
mf
mf
p
p


120
poco a poco crescendo
p
mf
125
mp

128

mf

f

131

p *poco a poco crescendo as before*

mp

p *poco a poco crescendo as before*

mp

p *poco a poco crescendo as before*

mp

p *poco a poco crescendo as before*

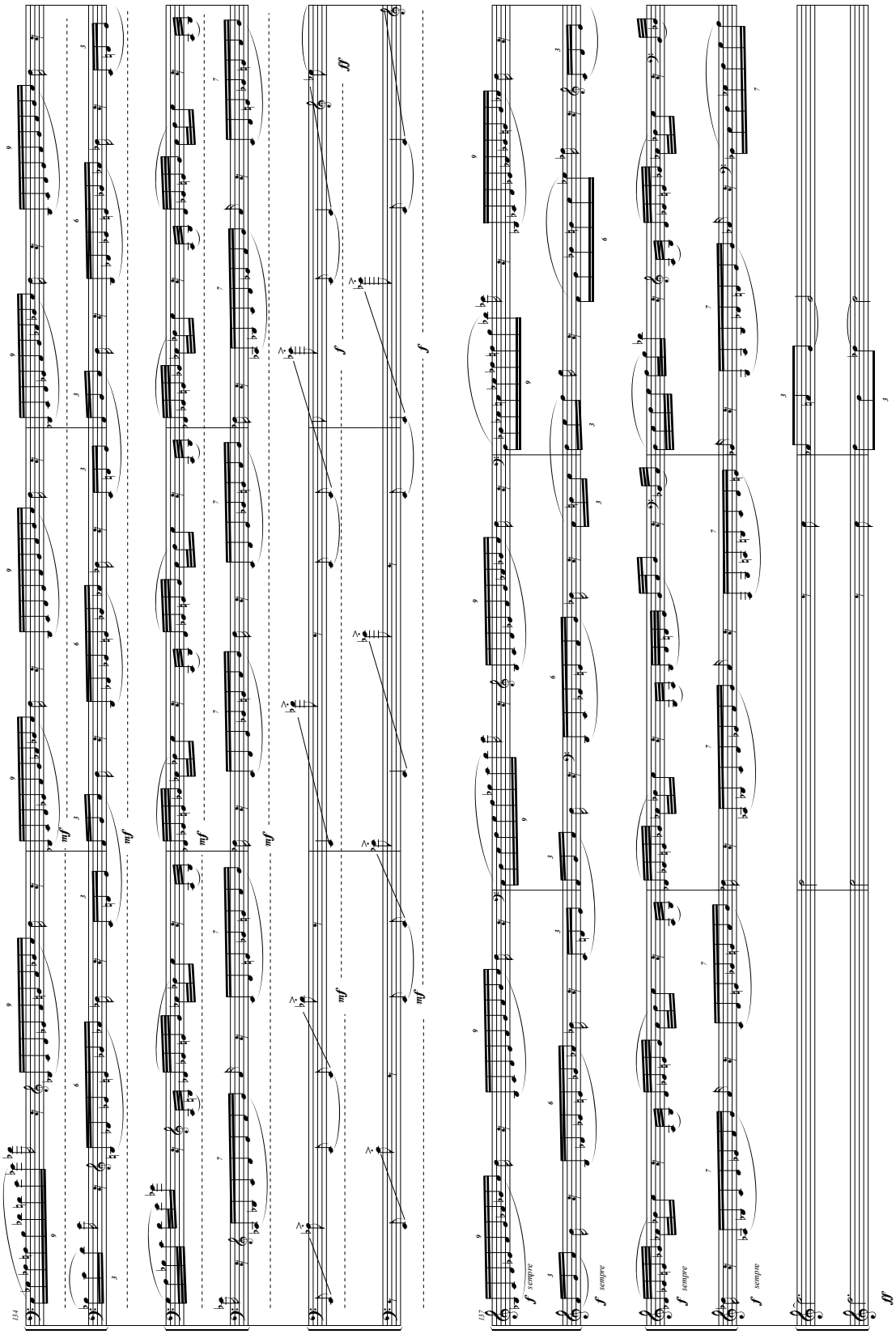
mp

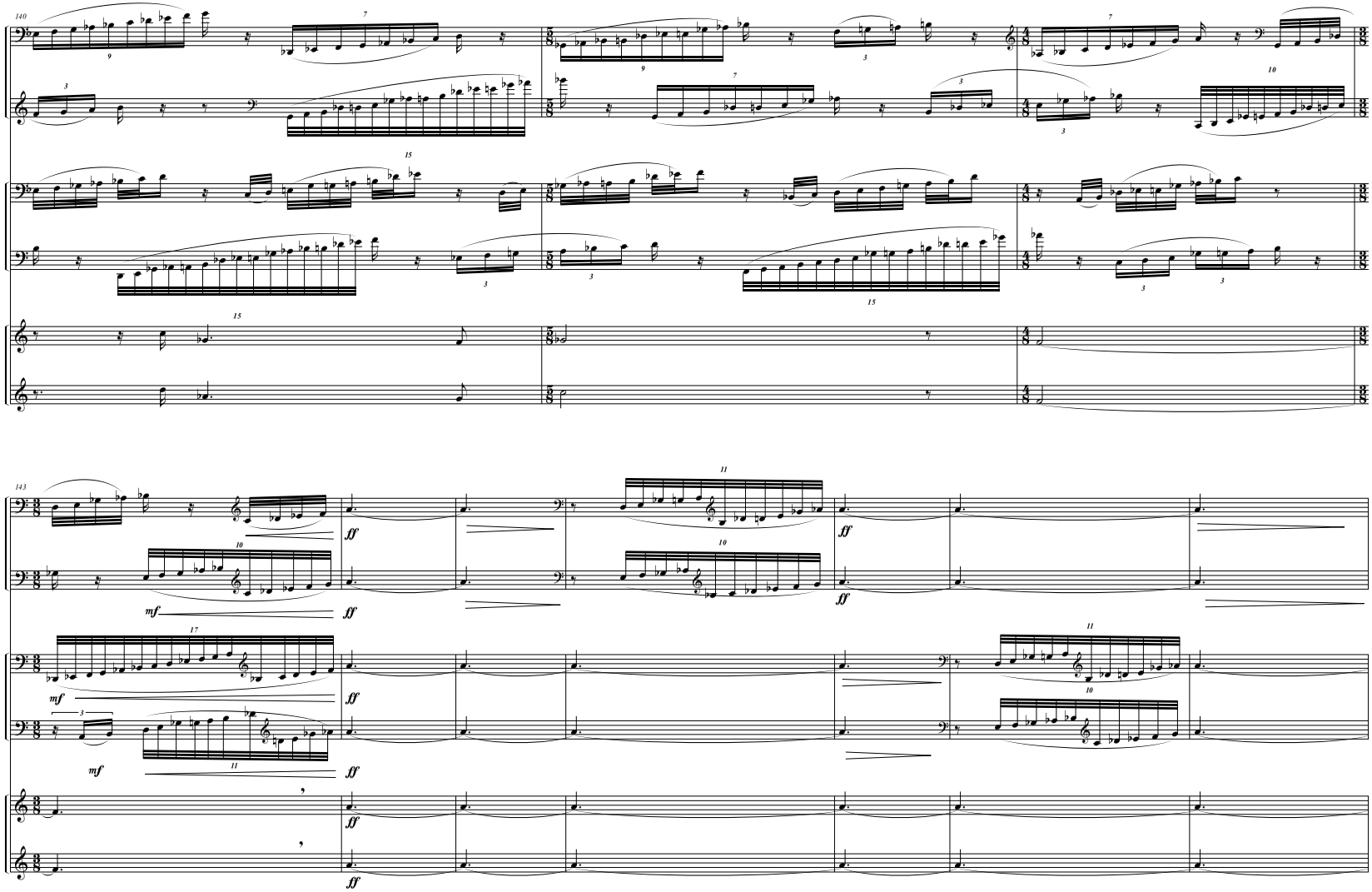
p *poco a poco crescendo*

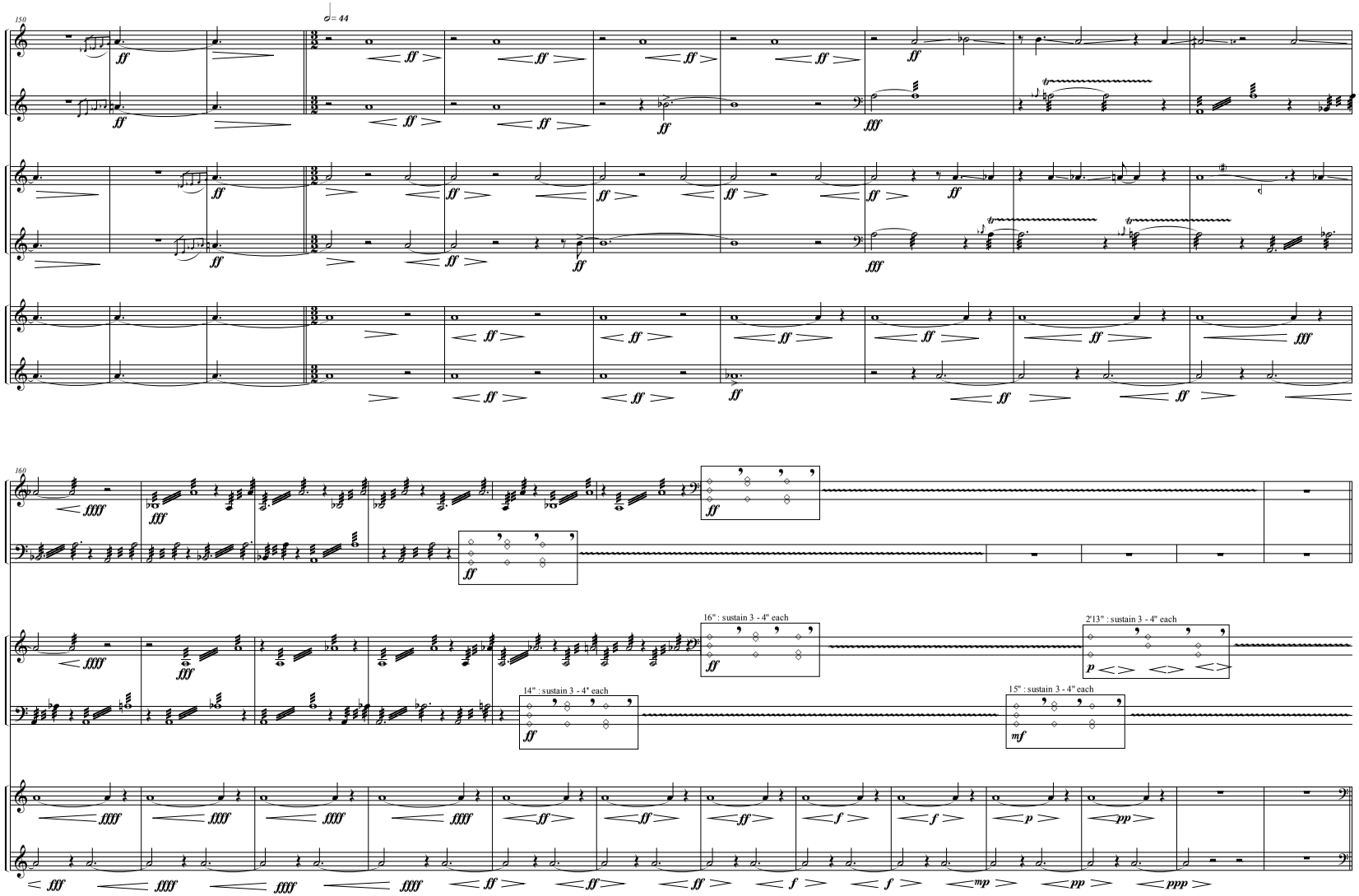
mp

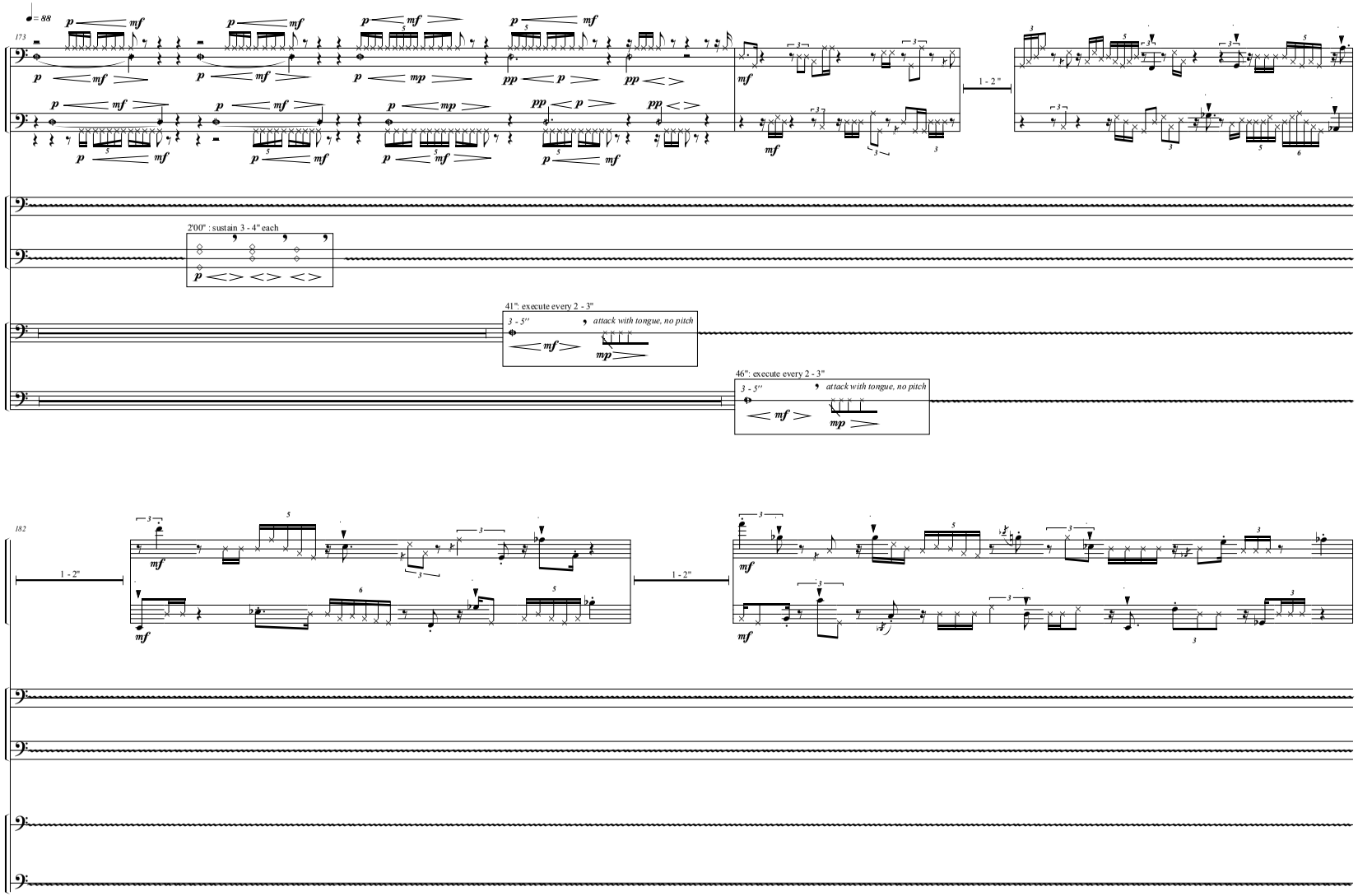
p *poco a poco crescendo*

mp


134
mf
mf
mf
mf
ff
f
f
137
f sempre
f sempre
f sempre
f sempre
ff


140
143
mf
ff


150
= 44
160
16" : sustain 3 - 4" each
2'13" : sustain 3 - 4" each
14" : sustain 3 - 4" each
15" : sustain 3 - 4" each


173
= 88
1 - 2"
2'00" : sustain 3 - 4" each
41": execute every 2 - 3"
3 - 5"
attack with tongue, no pitch
46": execute every 2 - 3"
3 - 5"
attack with tongue, no pitch
182
1 - 2"
1 - 2"

188

1 - 2"

1 - 2"

22": sustain 5 - 6"

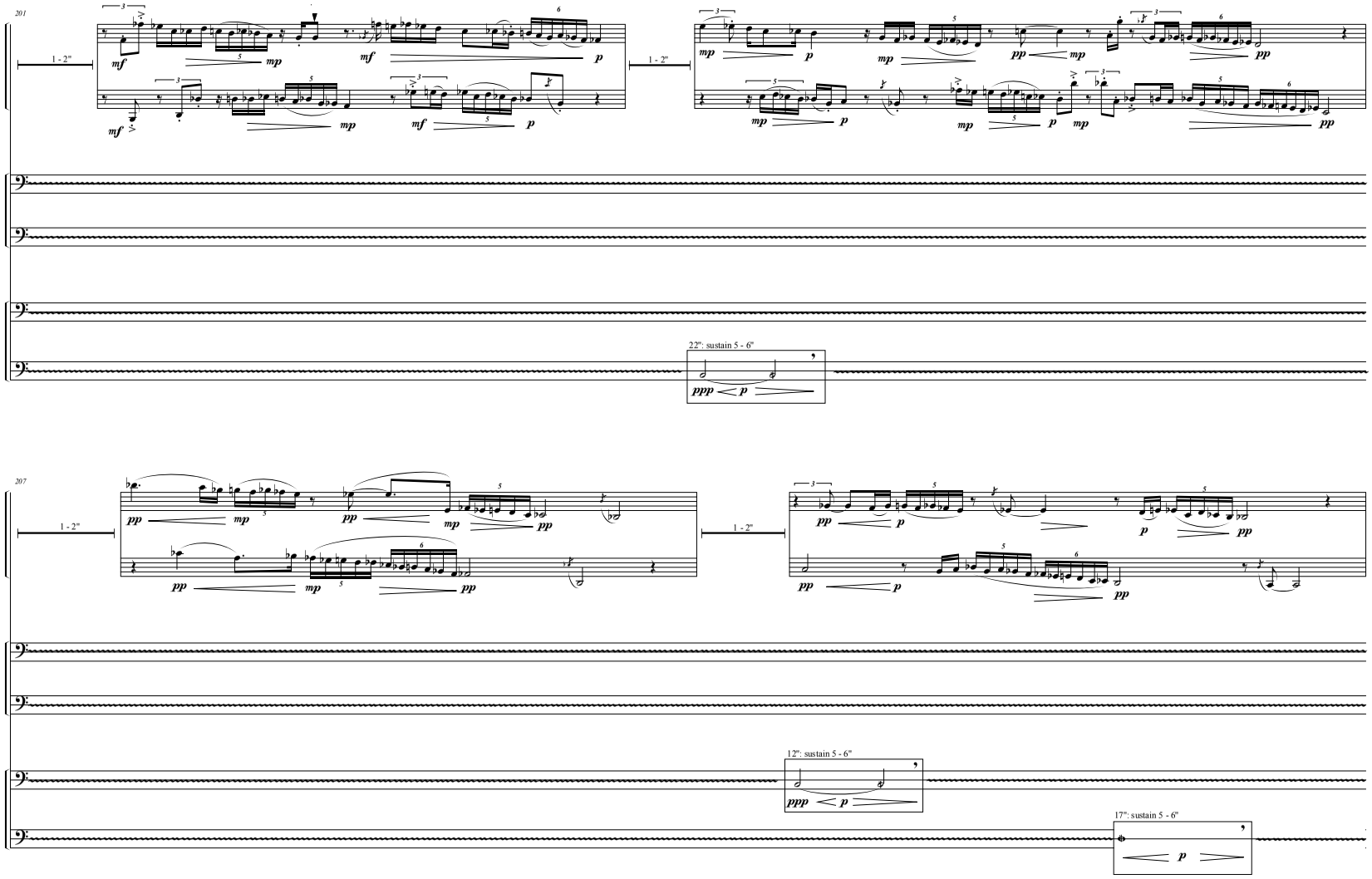
27": sustain 5 - 6"

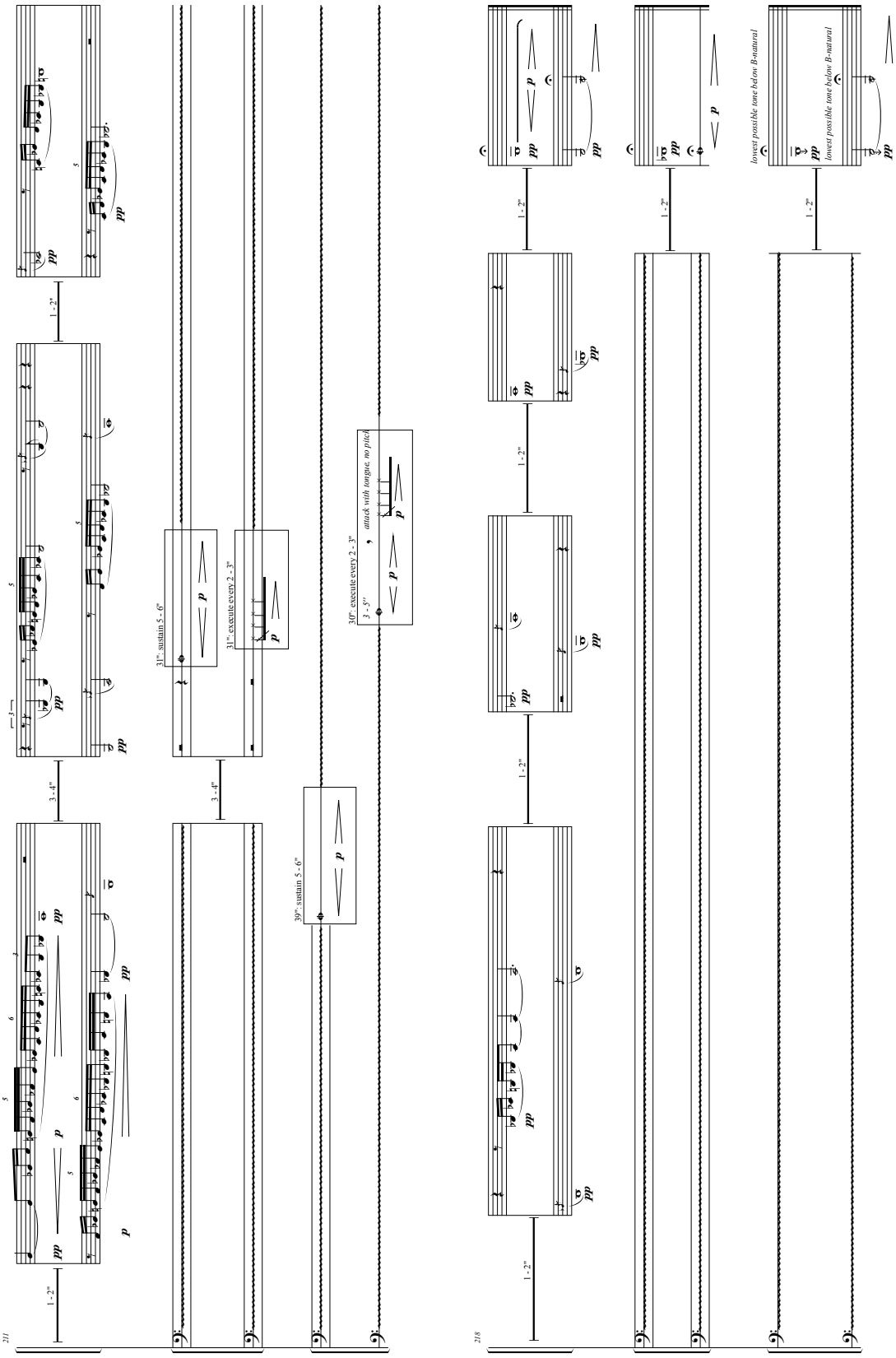
195

1 - 2"

1 - 2"

34": sustain 5 - 6"


201
1 - 2"
mf
mp
mf
p
1 - 2"
mp
p
mp
pp
mp
pp
mp
p
mp
p
mp
pp
22": sustain 5 - 6"
ppp
p
207
1 - 2"
pp
mp
pp
mp
pp
pp
mp
pp
1 - 2"
pp
p
p
pp
pp
p
pp
12": sustain 5 - 6"
ppp
p
17": sustain 5 - 6"
p


211
1 - 2"
3 - 4"
31": sustain 5 - 6"
31": execute every 2 - 3"
39": sustain 5 - 6"
30": execute every 2 - 3"
3 - 5"
attack with tongue, no pitch
218
lowest possible tone below B-natural
lowest possible tone below B-natural

II.

Activity and Presence

for cello and live processing

Activity and Presence:

- *I.* CD 1 Track 1 (4’07”)
- *II.* CD 1 Track 2 (9’39”)

Activity and Presence is a piece for solo cello and live processing, where the sonic material from the cello is manipulated in real time through a network of filtering, delays, and granulation. In addition, the cello performs in dialogue with pre-recorded material executed by the controller. The first movement of the piece focuses on dynamic activity: erratic, violent, and obnoxious. The second, indicative of presence, emphasizes the moment: stasis and reflection.

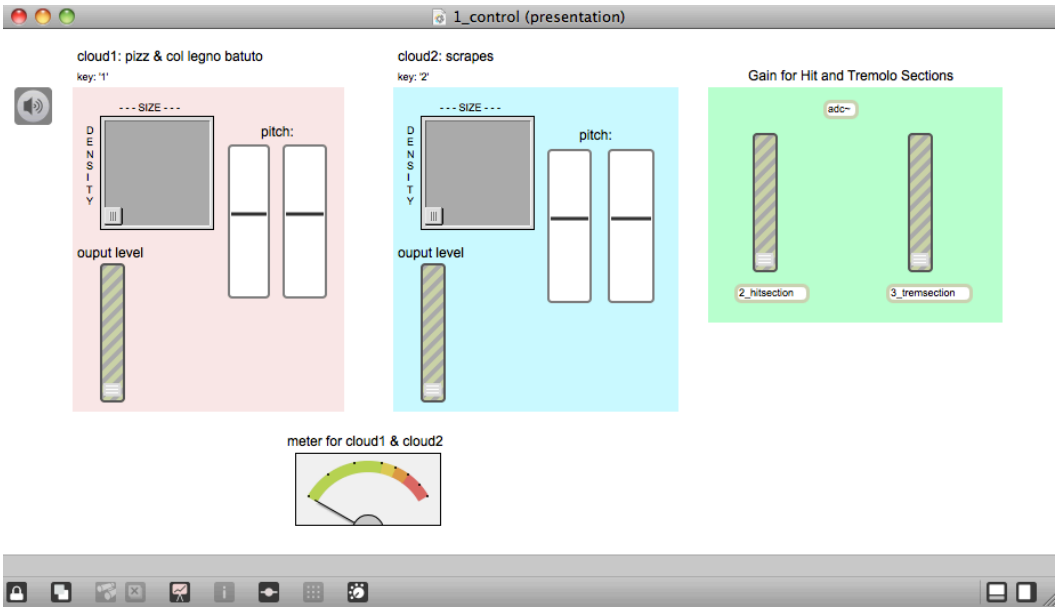
Activity and Presence

for cello and electronics

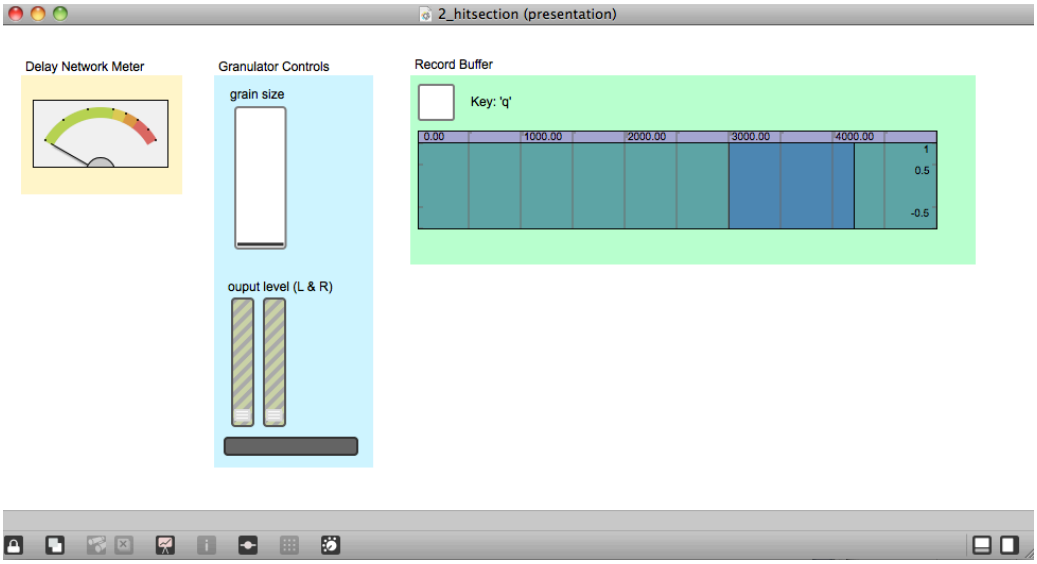
Brian Hansen

2010

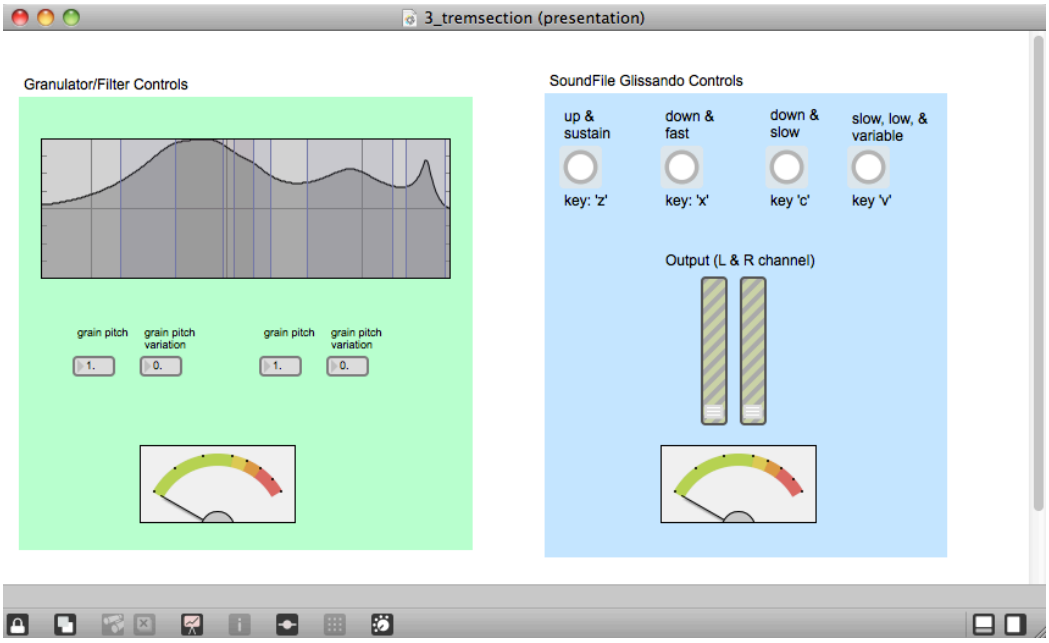
Max/MSP Patch Layout for Activity



The 1_control patch is the main control patch for Activity. Sound clouds of cello col legno hits are produced with controls highlighted in pink, and clouds of scrapes are produced with the controls in blue. Activity also has two subpatches: 2_hitsection and 3_tremsection. Each of these can be opened via the 1_control patch, and their gain input resides here (displayed in green).

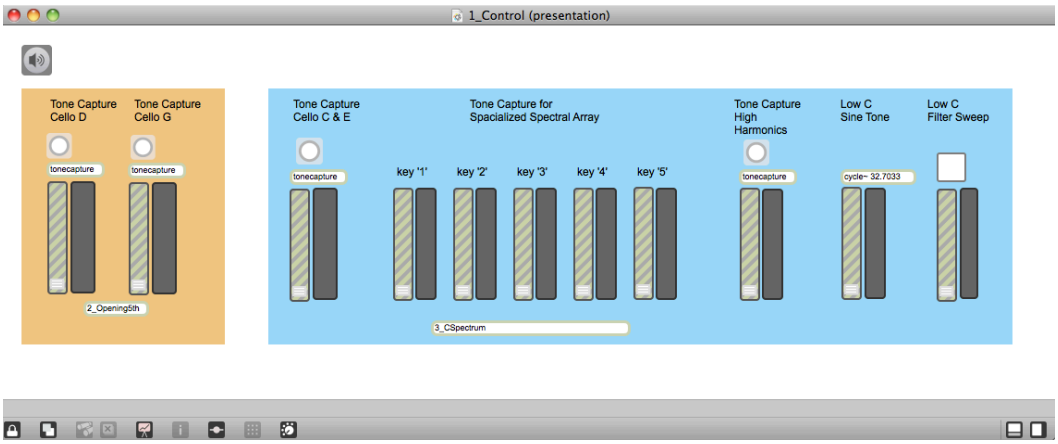


The 2_hitsecion patch can be opened from the 1_control patch, where its audio input levels are set. It contains a delay network, where the output level is highlighted in yellow. Audio input into this patch also is processed through a granulator (controls highlighted in blue). The output levels from the granulator are independent of the delay network. Finally, when triggered, an audio input into this subpatch is stored into a record buffer. Audio stored in this buffer is also output through the granulator and subsequently through the granulator output levels.

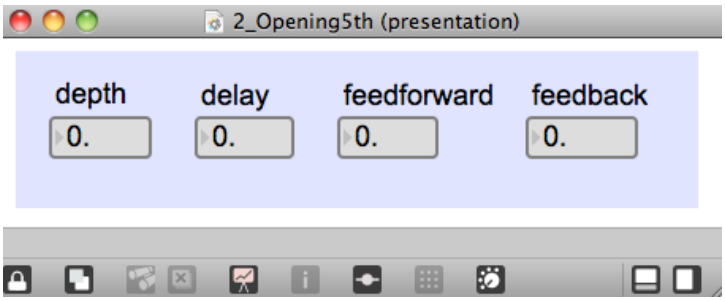


The subpatch 3_tremsection can be opened from the 1_control patch, where its audio input levels are set. This subpatch contains a delay network that runs through a filter array and then granulator before being output (in green). The filter can be manipulated via click & drag with the mouse over the filter display. Grain pitch and duration are also available for manipulation. A soundfile consisting of cello tremolo is stored in a buffer, which is manipulated by the controls highlighted in blue. Here, the playback speed of the audio file is increased or decreased to create glissandi. The output level for this buffer is independent from the live feed of audio that is processed through the filter and granulator

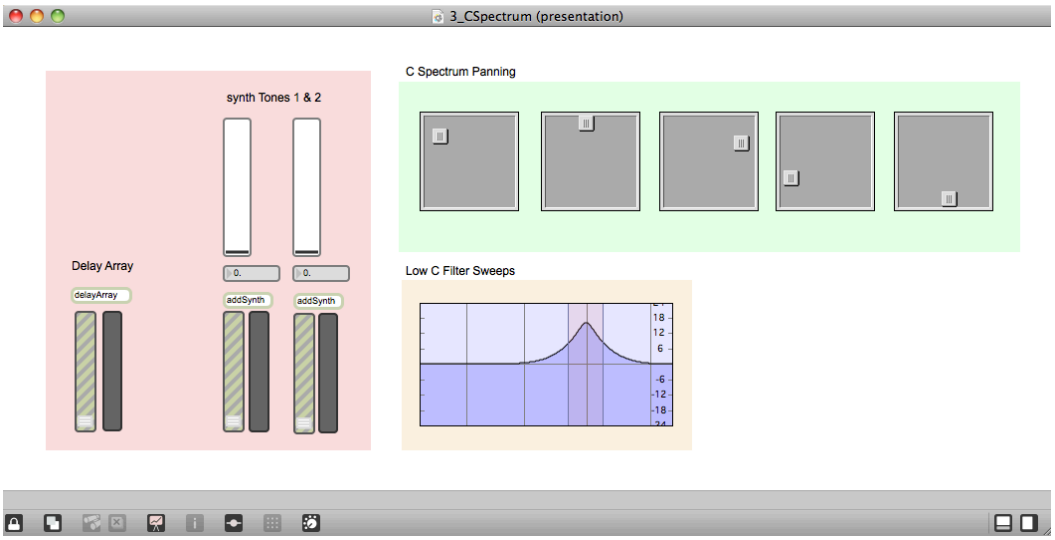
Max/MSP Patch Layout for Presence



The 1_Control patch is the main control patch for Presence. Throughout the piece cello tones are captured, sustained, and processed. Cello tones are to be captured into a tone capture buffer, where each buffer has an independent output level control. Tone capture buffers displayed in the patch correspond with directions for execution in the performance score. Presence also requires two subpatches: 2_Opening5th and 3_CSpectrum. Each of these can be opened via the 1_Control patch, and their gain input resides here.



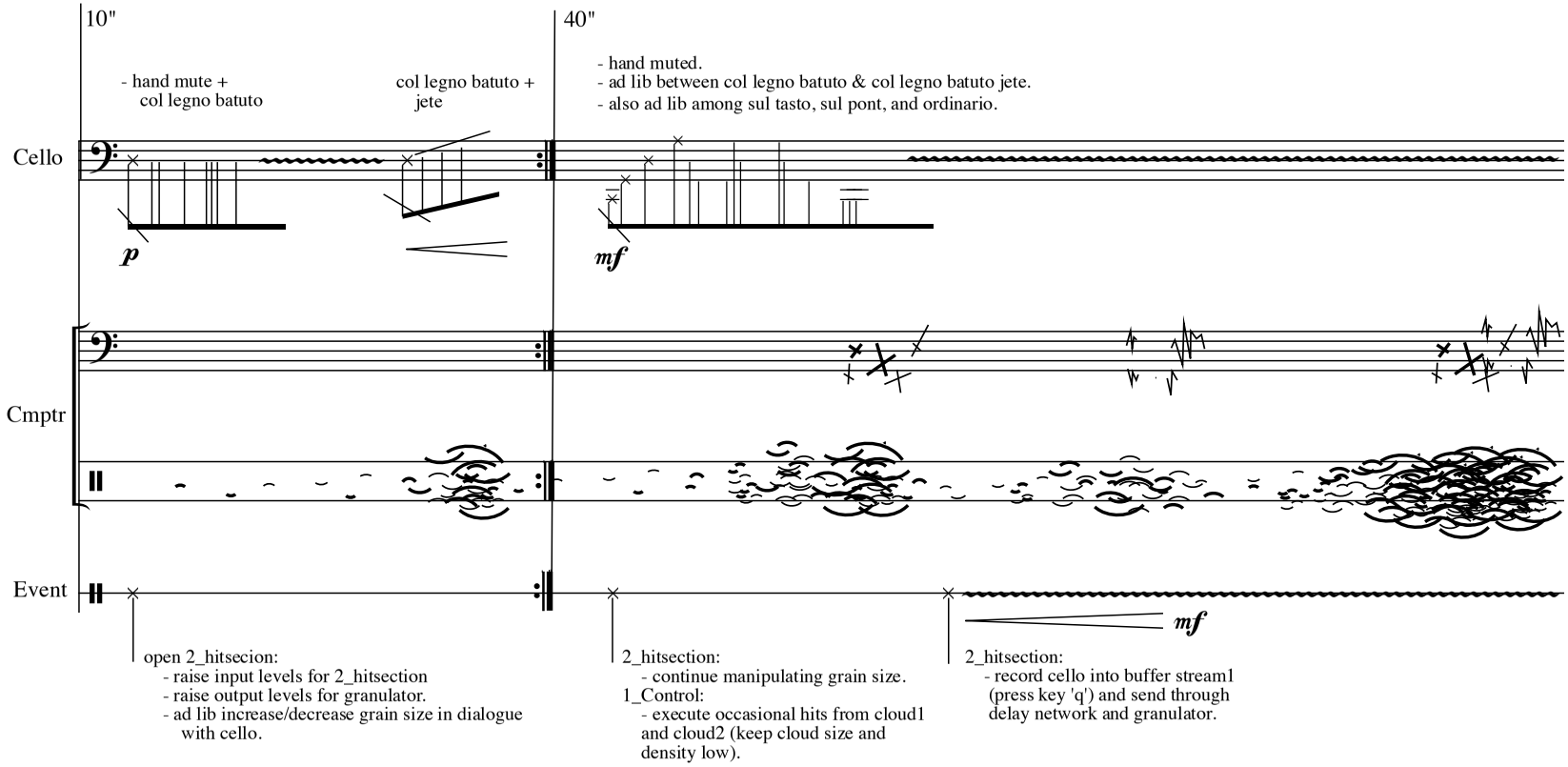
The 2_Opening5th subpatch can be opened via the 1_Control patch. This subpatch consists of a comb filter, where the controls to be manipulated are depth, delay, feedforward, and feedback.

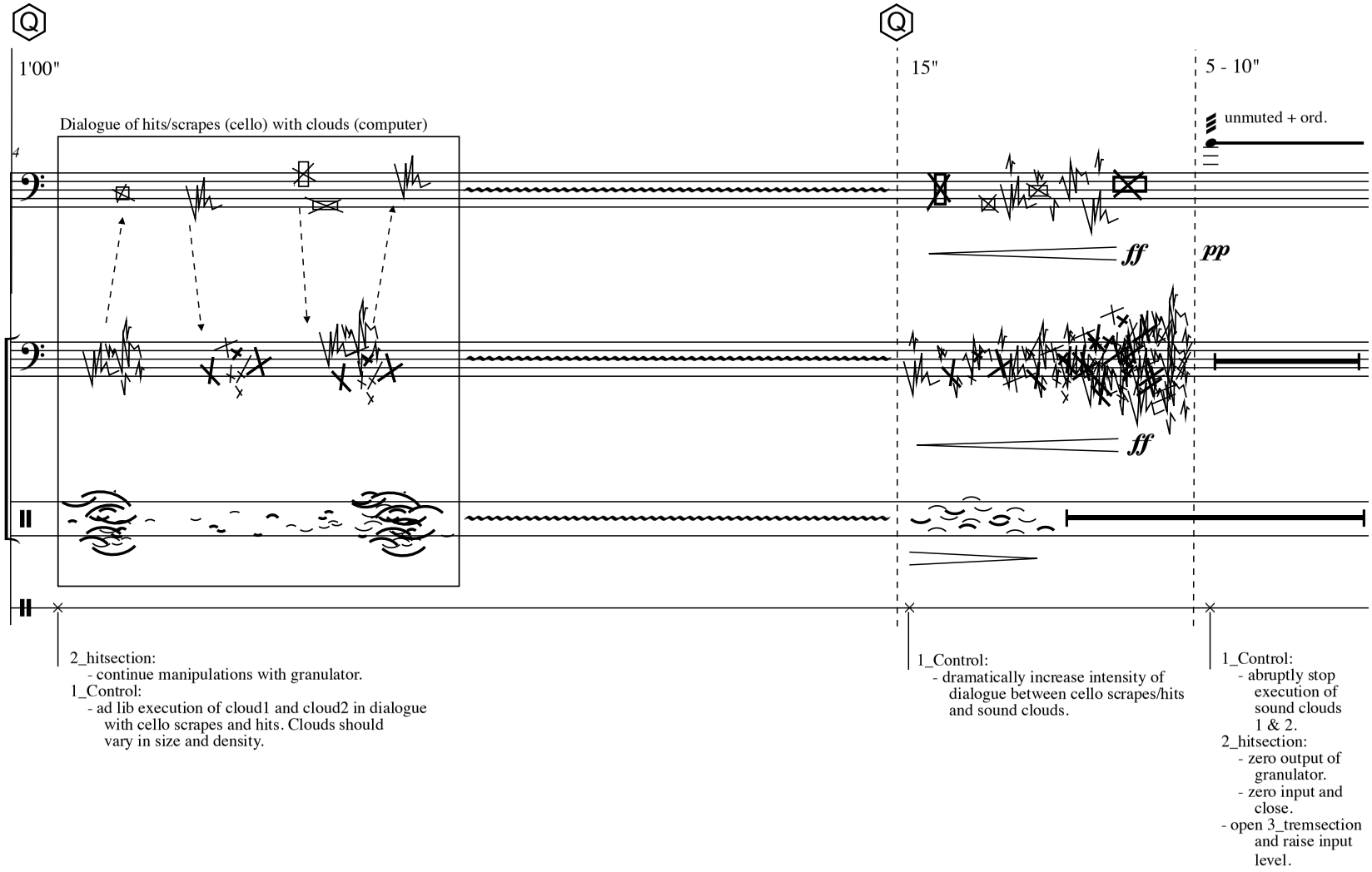


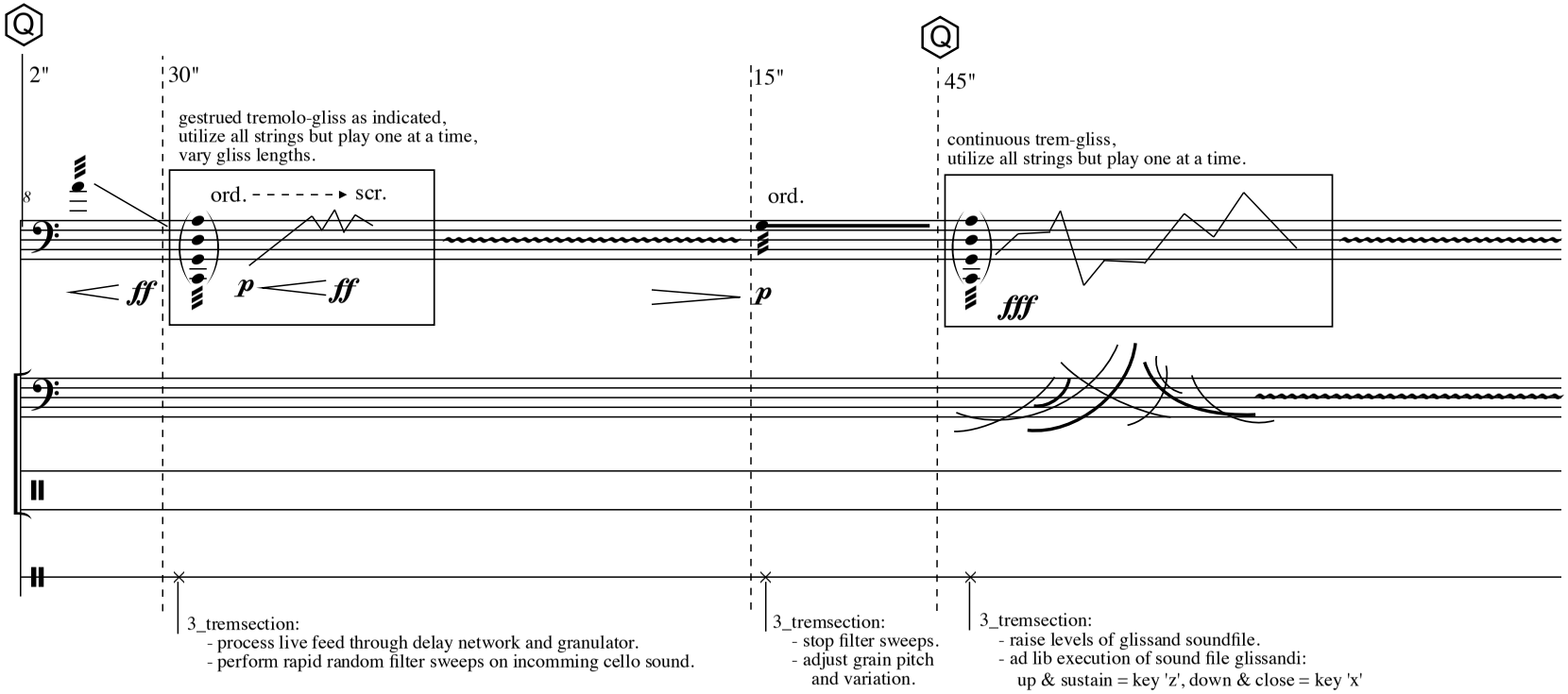
The 3_CSpectrum subpatch can be opened via the 1_Control patch. It contains output level controls for a delay array, and controls for two additive synthesis tones (both in pink). The synth tone controls manipulate pitch (upper sliders) and output level (lower sliders positioned next to level meters). In addition to these controls, the subpatch displays the spatial panning positioning of captured tones that are based on a harmonic series belonging to a fundamental of C. In addition, it displays the activity of automated filter sweeping over a droning low C. Neither of these displays requires user manipulation. They are present for monitoring purposes only.

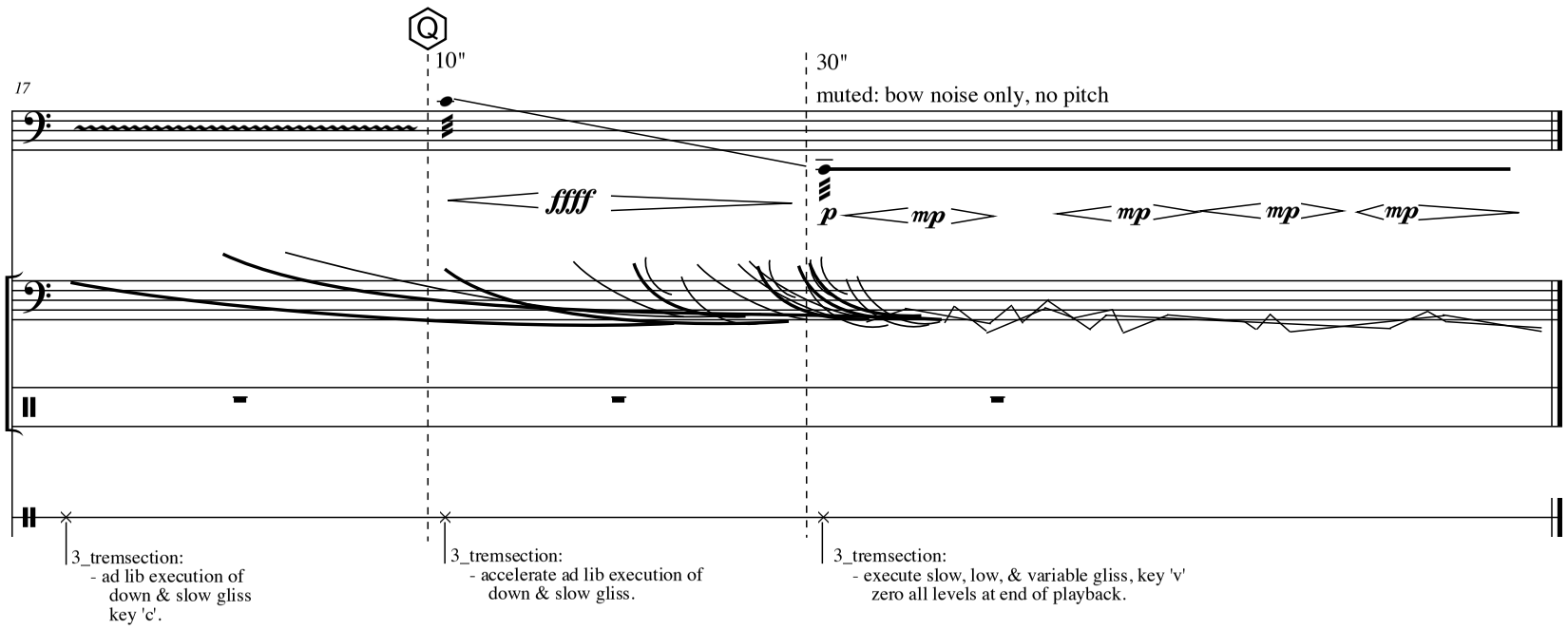
I.

Brian Hansen




Q
1'00"
Dialogue of hits/scrapes (cello) with clouds (computer)
4
Q
15"
5 - 10"
unmuted + ord.
ff
pp
ff
2_hitsection:
- continue manipulations with granulator.
1_Control:
- ad lib execution of cloud1 and cloud2 in dialogue with cello scrapes and hits. Clouds should vary in size and density.
1_Control:
- dramatically increase intensity of dialogue between cello scrapes/hits and sound clouds.
1_Control:
- abruptly stop execution of sound clouds 1 & 2.
2_hitsection:
- zero output of granulator.
- zero input and close.
- open 3_tremsection and raise input level.


Q
2"
30"
15"
Q
45"
gestrued tremolo-gliss as indicated,
utilize all strings but play one at a time,
vary gliss lengths.
ord.
scr.
ord.
continuous trem-gliss,
utilize all strings but play one at a time.
ff
p
ff
p
fff
3_tremsection:
- process live feed through delay network and granulator.
- perform rapid random filter sweeps on incomming cello sound.
3_tremsection:
- stop filter sweeps.
- adjust grain pitch
and variation.
3_tremsection:
- raise levels of glissand soundfile.
- ad lib execution of sound file glissandi:
up & sustain = key 'z', down & close = key 'x'


Q
10"
30"
17
muted: bow noise only, no pitch
ffff
p
mp
mp
mp
mp
3_tremsection:
- ad lib execution of
down & slow gliss
key 'c'.
3_tremsection:
- accelerate ad lib execution of
down & slow gliss.
3_tremsection:
- execute slow, low, & variable gliss, key 'v'
zero all levels at end of playback.

II.

Brian Hansen

10" | 2'00" | 30" | 20" | 10"

Cello

ordinario + non vibrato

ad lib bowing techniques in call & response
dialogue of sonic swells with computer.
Swells should occur while sustaining the G.
Swells should center on forte and include the
following bowing techniques ad lib:
- (sul pont, ord., or scratch tone)
- (non vibr, vibr, or tremolo)

ordinario + non vibrato

f *f* *ff* *p*

Cmptr

f *f* *f* *p*

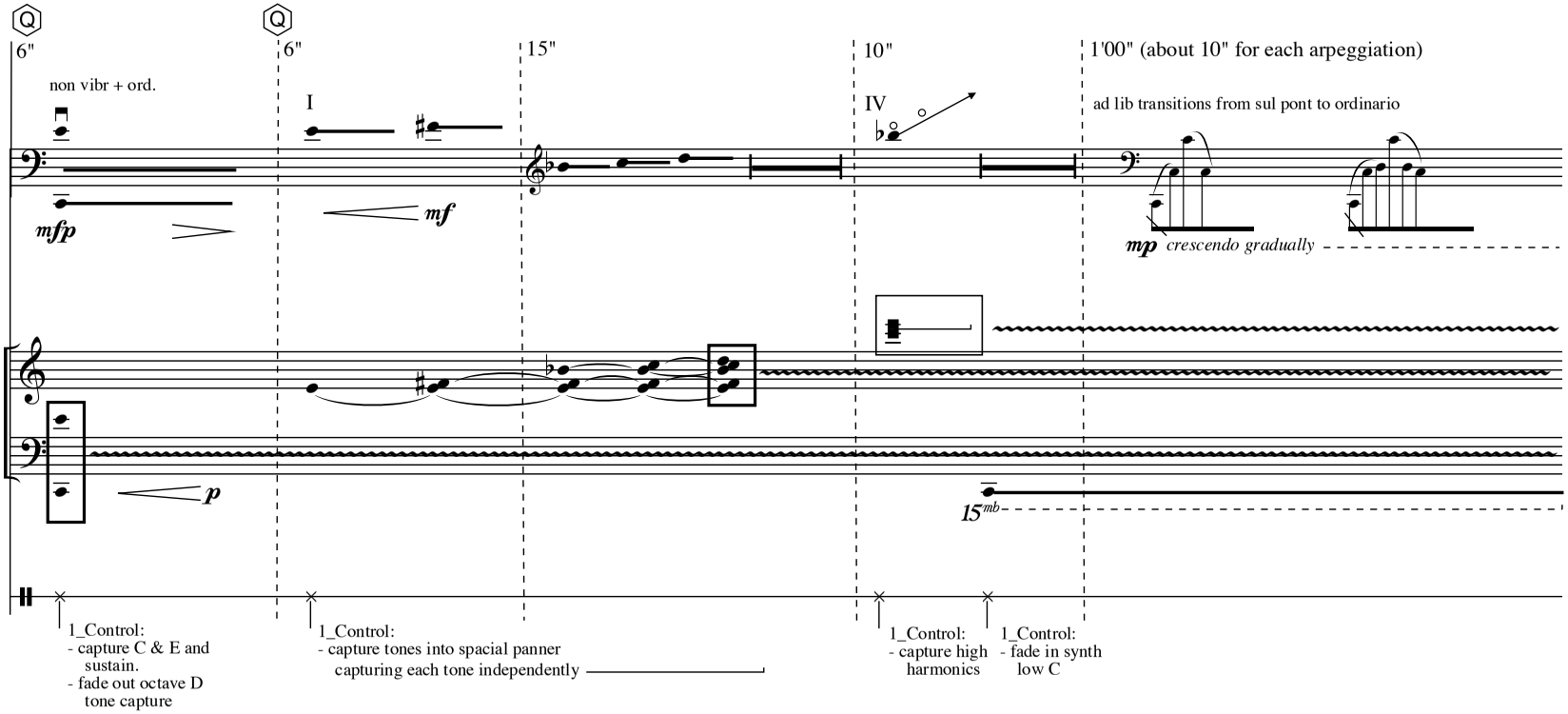
Notes

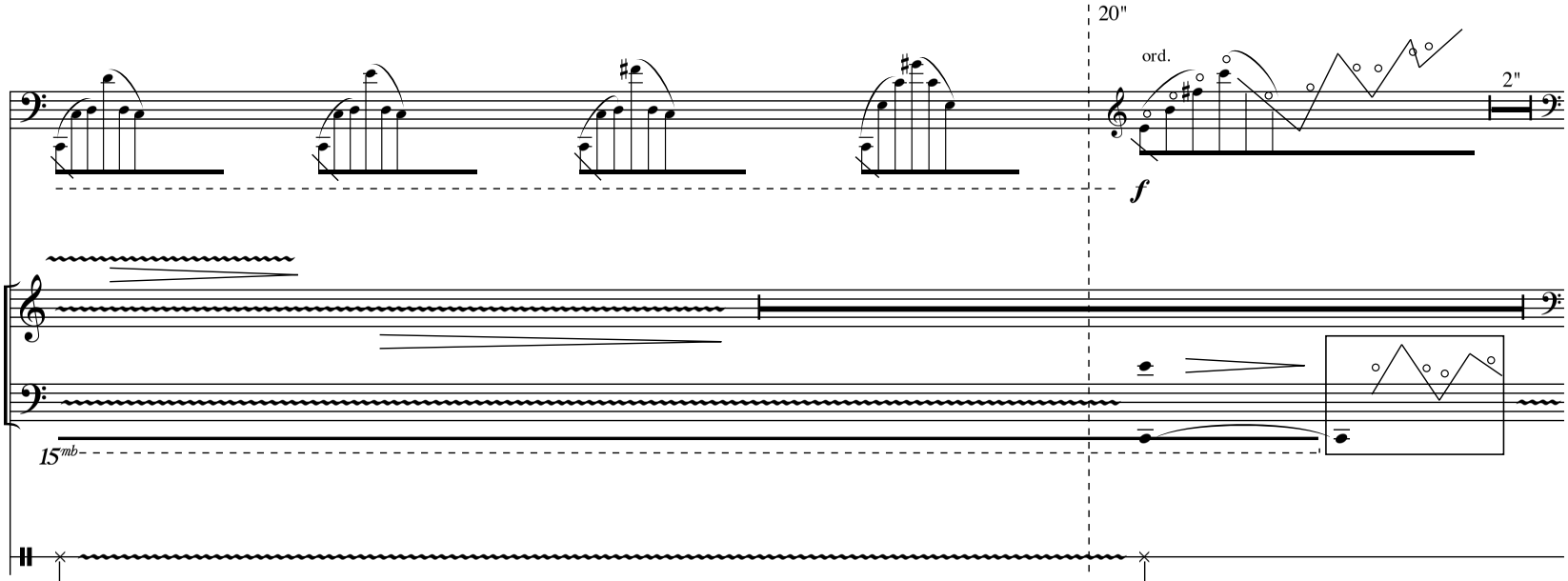
1_Control: capture cello tones
D & G and sustain.

- produce dialogue of sonic swells with cello,
ad lib processing within each swell,
with each swell centered on mf.
- sonic swells are produced via processesing the cello 'd' with
delay feedback as follows:
1. open 2_Opening5th and ad lib feedback
parameters as follows:
- 1st minute improvise with feedfwd, feedbck,
and delay only.
- 2nd minute improvise with all settings, gradually
increasing cycle and depth.

- 2_Opeining5th: clear processing effects
- depth, cycle, delay,
feedforward, and
feedback all go to 0.
- maintian gain = 1.0

1_Control:
- capture octave
into tone
capture D.
- fade out tone
capture G.


Q
6"
non vibr + ord.
mfp
p
Q
6"
I
mf
15"
10"
IV
1'00" (about 10" for each arpeggiation)
ad lib transitions from sul pont to ordinario
mp
crescendo gradually
15mb
1_Control:
- capture C & E and sustain.
- fade out octave D tone capture
1_Control:
- capture tones into spacial panner capturing each tone independently
1_Control:
- capture high harmonics
1_Control:
- fade in synth low C



- open 3_CSpectrum: fluctuate gain level of delay array.
- 1_Control: gradually fade out captured high harmonics and gradually fade out spacially revoloving captured tones.

- 3_Cspectrum: set delay network gain level at full.
- 1_Control: fade in sound file of low C with filter sweeping.

20"

- to be played with strong timbral expressivity.
- ad lib non vib to wide vib + sul pont to ord.

mf

20"

mp

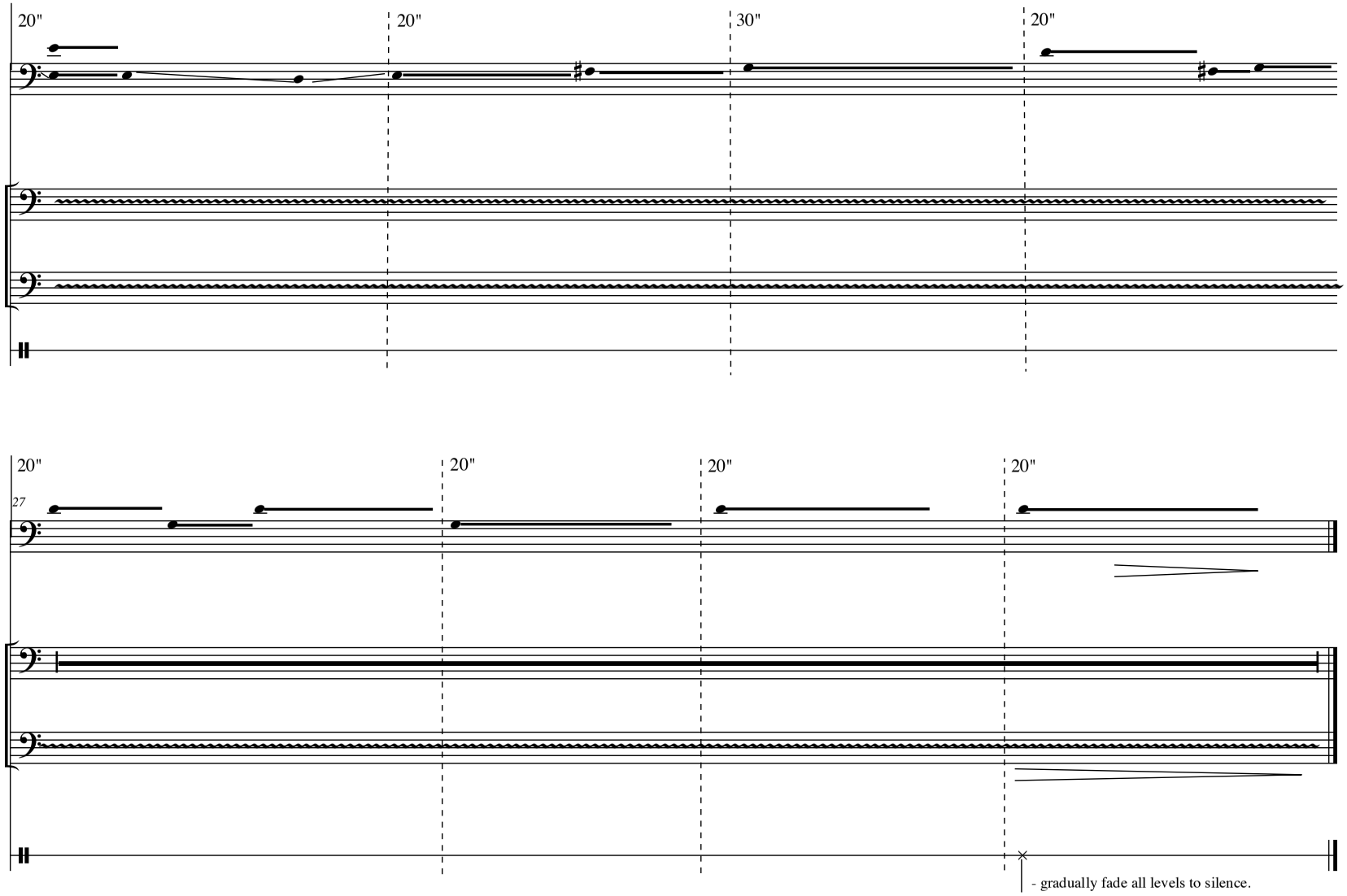
mp

30"

- 3_CSpectrum: produce slowly descending glissandi with synth tones. Each gliss should have a fade in and fade out, from and returning to silence. Maximum dynamic should be mp.

15"

20"


20"
20"
30"
20"
20"
20"
20"
20"
27
- gradually fade all levels to silence.

III.

the sky

for voice and live processing

the sky CD 1 Track 3 (5’38”)

This piece is a setting of the titular poem of e.e. cummings. The unique aspect of the poem is that it is seemingly structured non-linearly, as the poetic text appears scattered on the page. However, it is clear that the text forms groups that clearly progress phonetically when read left to right across the page. This piece is a sonic illustration of the poem’s phonetic progression and textual abstraction.

the sky

Text: e.e. cummings
Music: Brian Hansen
2009

Performance Notes

To the vocalist:

Performance:
The vocalist must sing and sustain each notated pitch for a minimum of two seconds in duration. This period of time allows the tone to be captured by the computer, creating a sustained drone. After the tone has been captured the singer should wait for a cue from the controller to sing the next pitch.

Notations:
The vocalist's staff is clefless. This staff has one line, which indicates the singer's central range of comfort. It is up to the singer to decide what this pitch should be. Pitches notated above or below this line should deviate from the singer's selected central pitch in accordance with its apparent distance from the line. It is up to the singer to decide what the amount of deviation will be. Nevertheless, relativity must be maintained such that if a certain pitch is notated higher than a preceding one, it must sound higher than the preceding one.

To the controller:

Tone Capture and Performance Playback:
The computer captures the sung pitches as notated on the staves titled ToneCap1, ToneCap2, ToneCap3, and ToneCap4. Once a tone is captured, it is the controller's responsibility to decide the levels at which each captured tone should be heard. The controller should gradually fade in and fade out the captured tone drones.

Text Handling and Performance Playback:
The text of the poem is to be recited and recorded in the form of syllables, words, and phrases as follows:

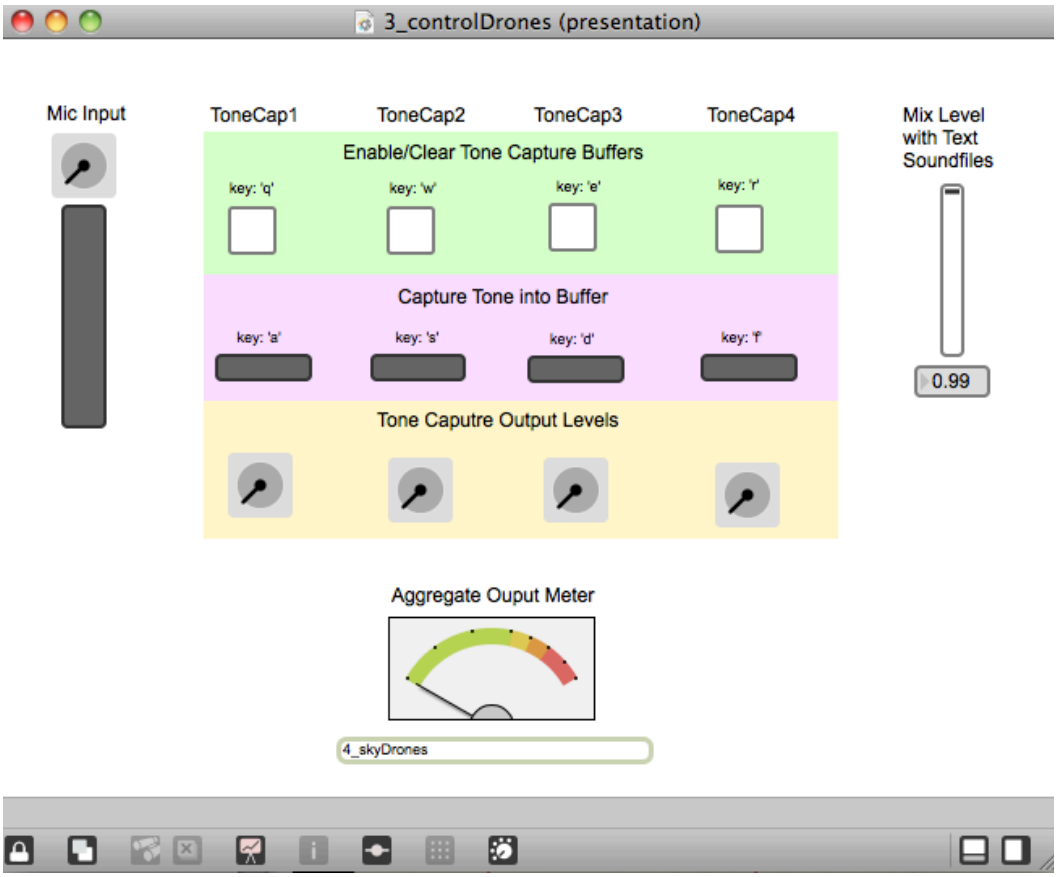
1. Syllables: each syllable of every word should be recited and recorded into a sound file. This file is to be referenced from the controlText patch. The patch must be programmed so that each syllable is read into to the syllable cluster routine.
2. Words: Each word from the poem must be recited and recorded into

an independent sound file. This file is to be referenced from the controlText patch. The patch must be programmed to read in desired words, as selected by the controller.

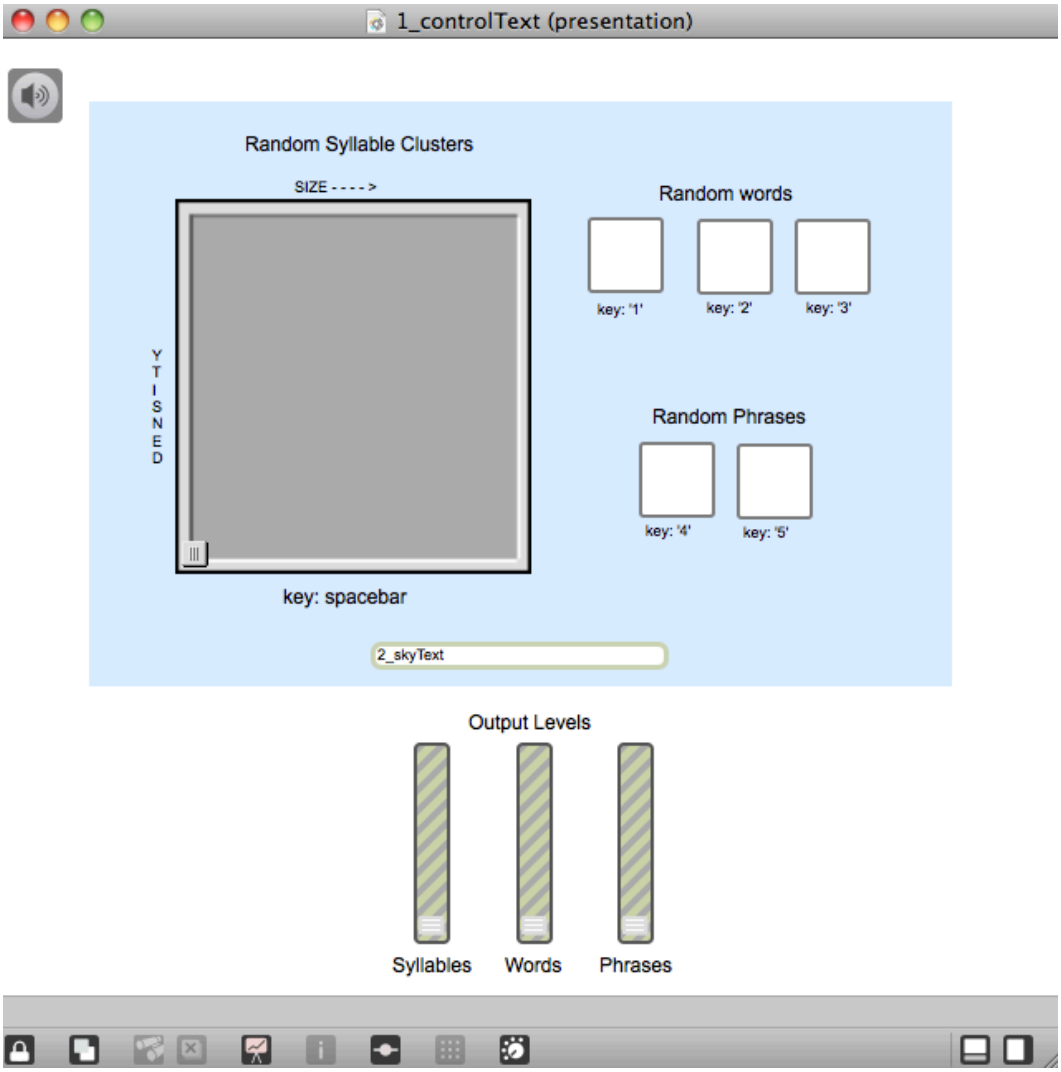
3 Phrases: Different phrases from the poem must be recited and recorded into an independent sound file. This file is to be referenced by the controlText patch. The patch must be programmed to read in desired phrases, as selected by the controller.

The poetic text is played back in the form of syllables, words, and phrases. Each type of text playback has its own control interface. The score indicates where and over what period of time each generator is to be used. Syllables should be played back using the syllable cluster generator. Words are played back using the word generator by executing any one of three buttons that trigger a random word. Phrases are played bayed back similarly to words, where any one of two buttons triggers a random phrase from the text.

Max Patch Layouts



The 3_controlDrones patch is the main control patch for the vocal level, tone captures, and adjusting the mix level with the poetic text playback. The mic input feeds directly into a delay array, whose output level is aggregated with the tone capture buffers. There are four tone capture buffers that must be controlled. Each buffer can be enabled or cleared and re-enabled with the buttons in the green area. The meters in the purple area indicate the audio level stored in the tone capture buffers. The output levels of each buffer are determined by the controllers in the yellow area. The aggregate level of all tone capture outputs and mic outputs are displayed by the Aggregate Output Meter.

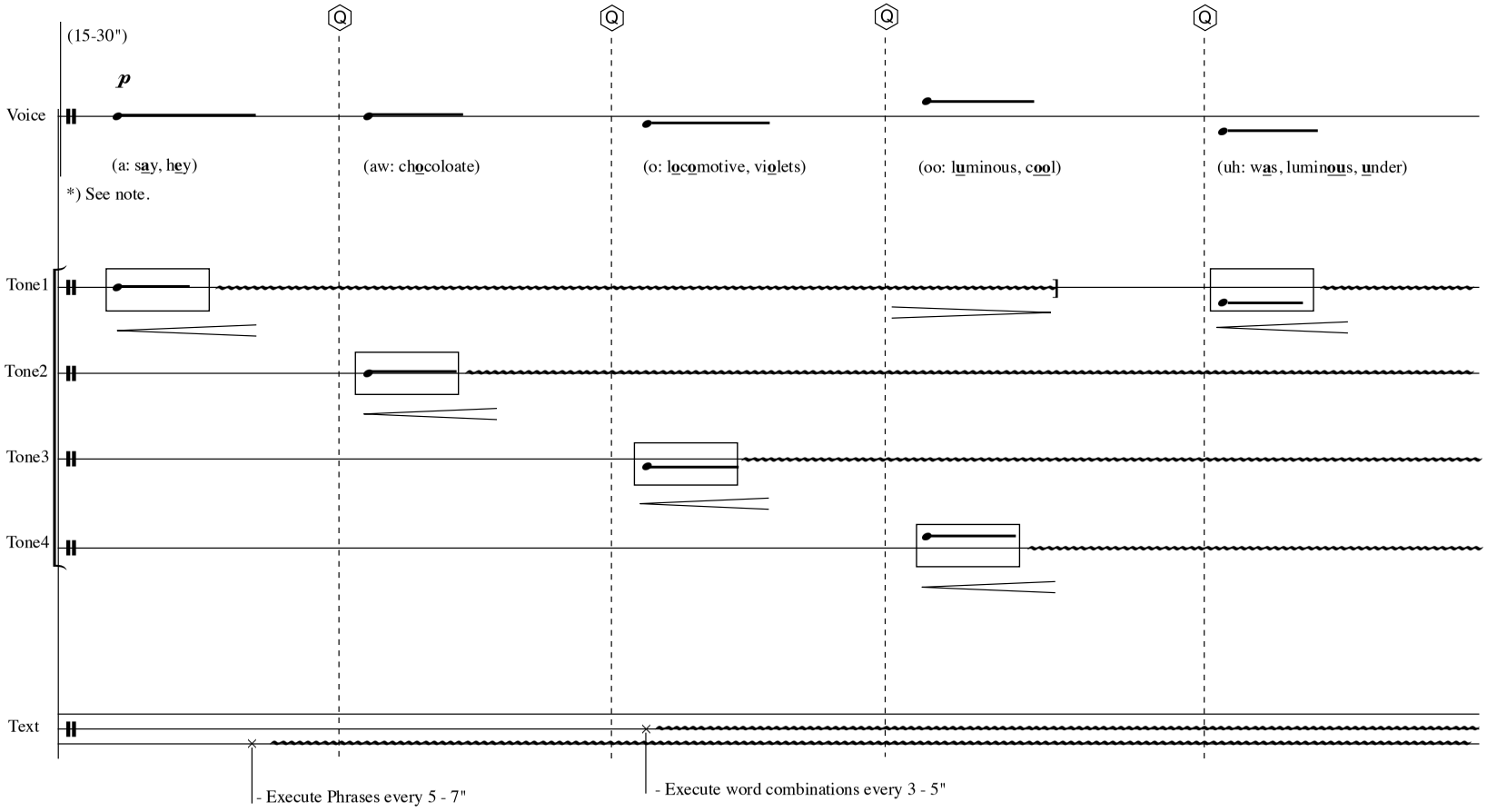


The 1_controlText patch is used to control playback of the pre-recorded recitation of the poetic text. The text is played back in the form of syllables, words, and phrases. Random syllable clusters are triggered via the spacebar key, and are uniquely determined by where the curser is placed inside the syllable cluster box. The size of the clusters increases from left to right, and cluster density increases from bottom to top. Thus, if the curser is placed in the upper right, this will produce a cluster of the highest possible density and size. Placement of the curser is indicated in the score as (size, density). For example, (H, H) should be interpreted as highest size and highest density cluster. Words are randomly selected and played back by triggering any one of the three Random Words boxes. Random phrases are played back by triggering either of the two Random Phrases boxes. The output level of each text type is independently set by its designated slider at the bottom of the patch.

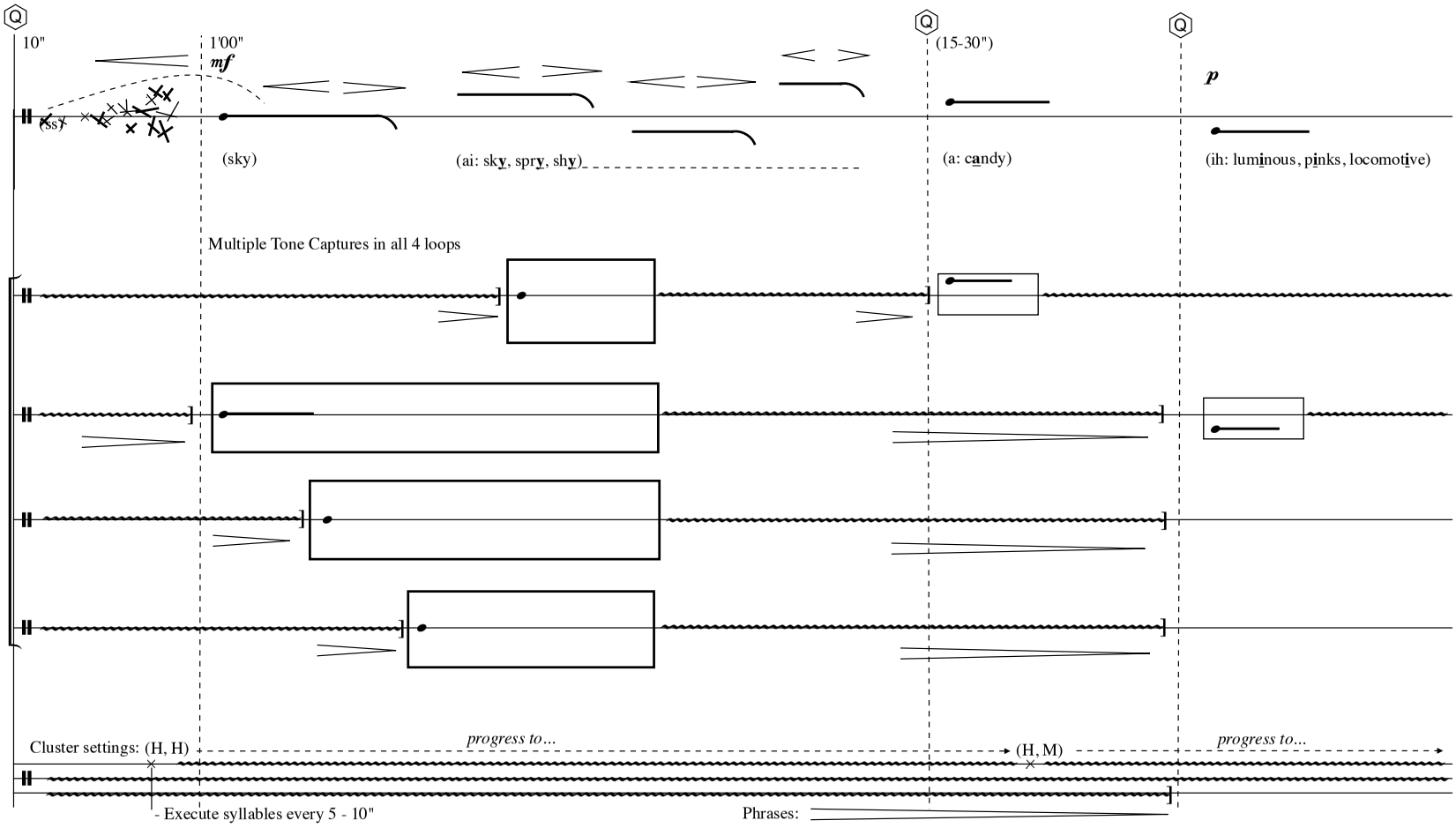
the sky

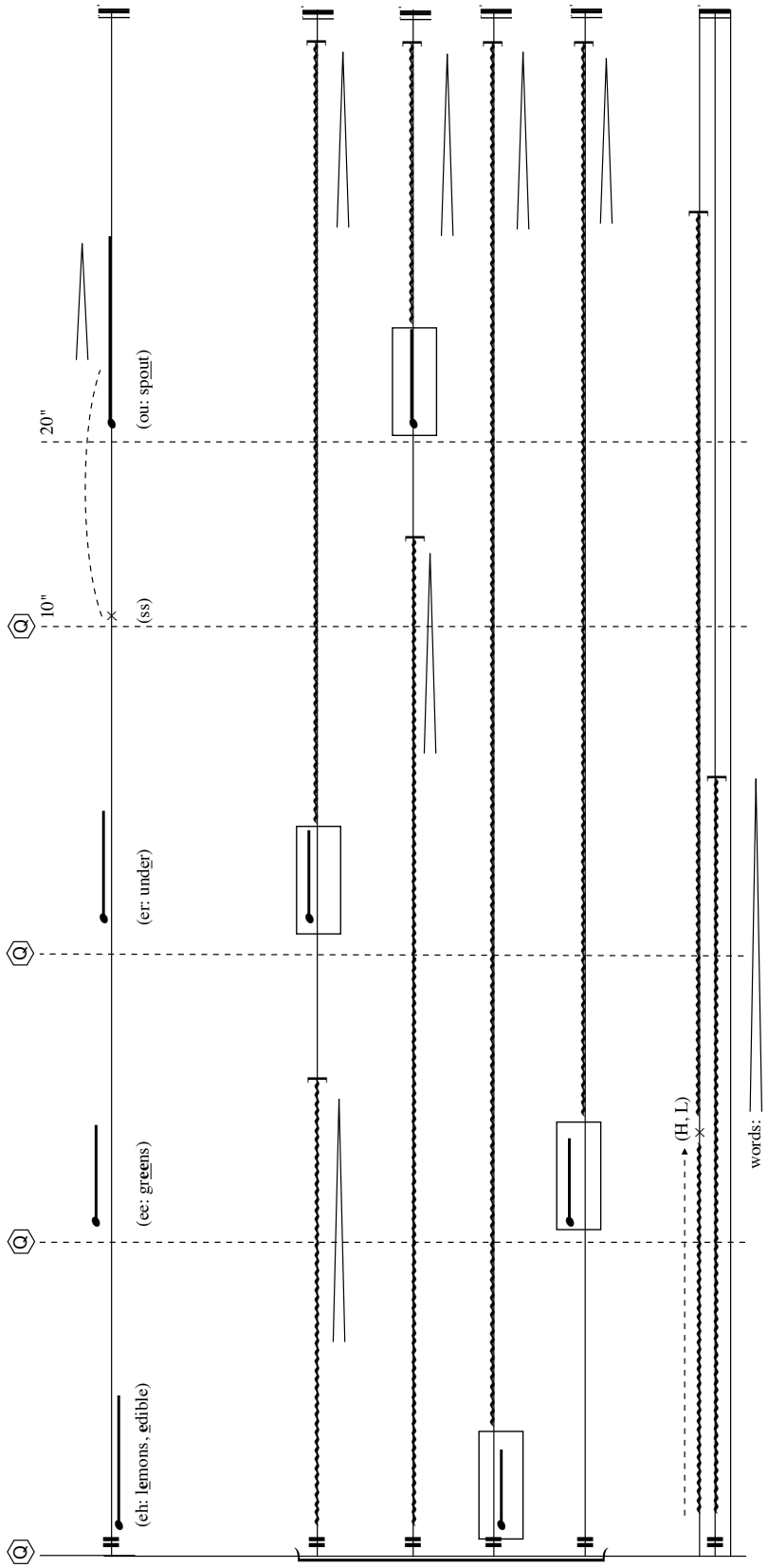
e.e. cummings

Brian Hansen



*) NOTE: Process voice through delay network throughout the entire duration of the piece.


Q
10"
1'00"
mf
(ss)
(sky)
(ai: sky, spry, shy)
Q
(15-30")
(a: candy)
Q
p
(ih: luminous, pinks, locomotive)
Multiple Tone Captures in all 4 loops
Cluster settings: (H, H)
progress to…
(H, M)
progress to…
- Execute syllables every 5 - 10"
Phrases:


(eh: lemons, edible)
(ee: greens)
(er: under)
(ss)
(ou: spout)
10"
20"
(H, L)
words:

IV.

Studies of Sonic Process

for player piano and live processing

Studies of Sonic Process:

- *Out of One* CD 1 Track 4 (2’51”)
- *Pythagoras* CD 1 Track 5 (1’59”)
- *Intensities* CD 1 Track 6 (7’25”)
- *Streaming* CD 1 Track 7 (3’36”)
- *Phasing Arpeggi* CD 1 Track 8 (6’35”)
- *From the Root* CD 1 Track 9 (5’11”)
- *Harmony* CD 1 Track 10 (3’56”)

These player piano studies focus primarily on sonic production. They emphasize the realization of sonic textures, objects, gestalt, and affect. Each sonic “theme” is produced algorithmically, where the technical limits of the player piano are pushed to an extreme in dynamics, speed, quantity, and density.

Studies of Sonic Process

for player piano and computer

Brian Hansen

2012

Overview

Studies of Sonic Process consists of seven pieces individually programmed in Max/MSP, which are to be executed via player piano. Some of the pieces are automated, while others require varying degrees of performance by the controller. Execution and performance instructions are displayed within each Max program and are summarized below.

I. OUT OF ONE

The progression of *Out of One* is fully automated. The controller is only required to start and stop the piece. The piece can be started and stopped by executing the instructions in the ACTION window at their corresponding point in time indicated in the TIME window.

TIME	ACTION
0"	Click : start.
2'40"	Click : stop. Click when repeated reach the high B natural of the piano.

II. PYTHAGORAS

Pythagoras consists of an automated sequence that increases in speed as time passes. The controller is required to break the cycle of the accelerating sequence and bring it to a stop. This is accomplished by performing the instructions in the ACTION window at their corresponding time in the TIME window to the left.

TIME	ACTION
0"	Key: '1': initiate main sequence.
1'30"	Key '2': cut speed and dynamics.
1'40"	Key '3': initiate ritard.
1'50"	Key '4': press key when note has reached the top of the piano's range.

III. INTENSITIES

Intensities consists of four independent pitches that pulse synchronously throughout but have asynchronous dynamic swells. The duration of each swell is defined by the swell length indicated in the ACTION window. The controller must direct when swell lengths change by following the guidelines indicated in the ACTION and corresponding TIME windows.

TIME	ACTION
0"	Toggle on ☐ : start. Swell length = 40.
60"	Key '1': swell length = [120, 180].
2'00"	Key '2': swell length = 10.
2'30"	Key '3': swell length [200, 250].
4'30"	Key '4': swell length = 30.
5'00"	Key '5': swell length = 100.
6'15"	Toggle each on ☐ ☐ ☐ ☐ : initiate ending.

IV. STREAMING

The progression of *Streaming* is largely automated. The controller is required to start the piece, converge the streams, and stop the piece. Accomplish this by following the ACTION and TIME instructions.

TIME	ACTION
0"	Toggle on ☐ : start.
3'15"	Toggle on ☐ : convege streams.
3'25"	Toggle on ☐ : enable ending.

V. PHASING ARPEGGI

Phasing Arpeggi requires the most attention in terms of performance by the controller. The controller should follow the script defined below to execute the progression of the piece. Unlike the other pieces in the set, there is a DURATION corresponding to an instruction in the ACTION window. This means the action should be in effect for the corresponding duration. For example, ACTION **Toggle 'A' on** should be in effect for a DURATION of **8 – 10 cycles**. Note that a cycle is an arpeggiation metric. It is the time is takes to complete one arpeggiation. For example, 8 cycles would be the duration of 8 arpeggiations.

DURATION	ACTION
8 - 10 cycles	Toggle 'A' on.
3 - 6 sec.	Toggle 'A' off.
8 - 10 cycles	Toggle 'A' on.
3 - 6 sec.	Toggle 'A' off.
12 - 14 cycles	Toggle 'A' on.
3 - 6 sec.	Toggle 'A' off.
8 - 10 cycles	Toggle 'B' on.
3 - 6 sec.	Toggle 'B' off.
8 - 10 cycles	Toggle 'B' on.
3 - 6 sec.	Toggle 'B' off.
22 - 26 cycles	Toggle 'C' on.
3 - 6 sec.	Toggle 'C' off.
12 - 14 cycles	Toggle 'D' on.
3 - 6 sec.	Toggle 'D' off.
22 - 26 cycles	Toggle 'C' on.
3 - 6 sec.	Toggle 'C' off.
22 - 26 cycles	Toggle 'A' on.
8 - 10 sec.	Toggle 'A' off.

DURATION	ACTION
12 - 16 cycles	Toggle 'Main' on. Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
12 - 16 cycles	Key '3'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
12 - 16 cycles	Key '4'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '3'.
12 - 16 cycles	Key '4'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
18 - 22 cycles	Key '5'.

DURATION	ACTION
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
12 - 16 cycles	Key '6'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '3'.
12 - 16 cycles	Key '4'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '5'.
8 - 12 cycles	Key '3'.
16 - 20 cycles	Key '6'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
8 - 12 cycles	Key '1'.
8 - 12 cycles	Key '2'.
24 - 32 cycles	Key '6'.
	Toggle 'Main' off.

VI. FROM THE ROOT

The progression of *From the Root* is fully automated. The controller is only required to start the piece. Accomplish this by following the ACTION and TIME instructions.

TIME	ACTION
0"	Toggle each on ☐ ☐ ☐ : initialize chord streams.
0"	Click ◯ : start.
5'00"	When the counter reaches 1000 the piece will stop automatically: ▶0

VII. HARMONY

The progression of *Harmony* is largely automated. The controller is required to start and end the piece. Accomplish this by following the ACTION and TIME instructions.

TIME	ACTION
0"	Click ◯ : load midi.
0"	Toggle on ☐ : start.
3'20"	Toggle on ☐ : ending. NOTE: toggle after either 8 or 12 cycles of the overtone sequence above the piano's lowest Gb.

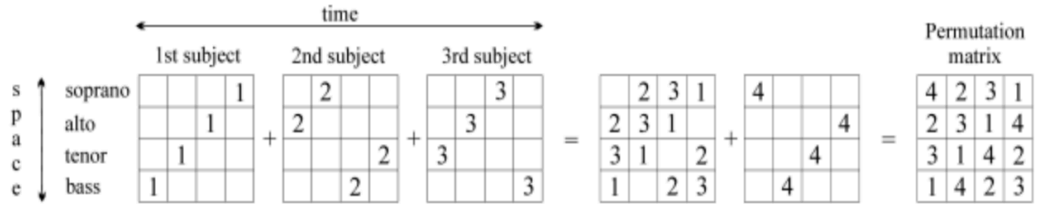
V.

Completion of J.S. Bach's *Contrapunctus XIV* from *The Art of Fugue*

Contrapunctus XIV Completion CD 1 Track 11 (10'22")

Contrapunctus XIV is the final fugue in J.S. Bach's seminal work *The Art of Fugue*. The fugue was left unfinished, where it abruptly ends with Bach spelling his name musically in the final fugue subject presented. Many have posited how it may have been completed, and most scholars agree that although the fugue in its unfinished state is a triple fugue, it was most likely intended to be a quadruple fugue, where the main subject of the *The Art of Fugue* was to make a final appearance. In particular, composer Zoltan Goncz presents a compelling argument for this, showing how the introduction of the first three subjects nearly complete a permutation matrix. The permutation matrix can ultimately be completed by the reappearance of a fourth subject - posited to be the main theme.

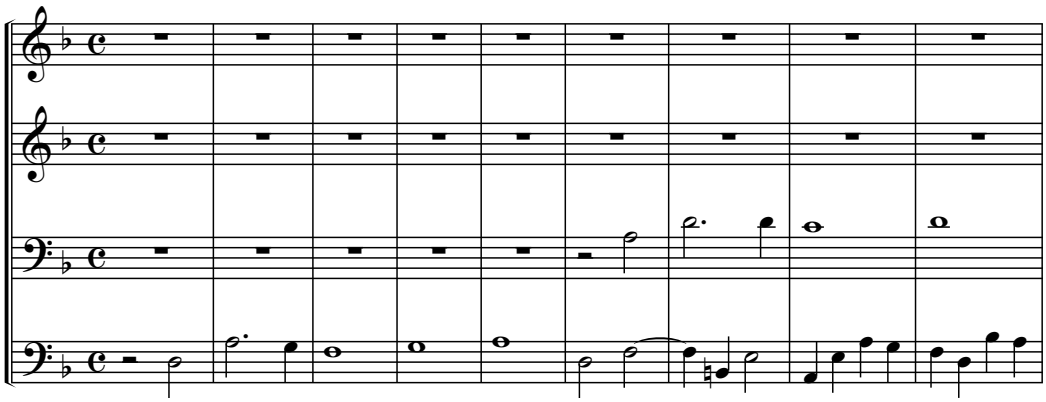
Figure 9. The Permutation Matrix in Contrapunctus XIV

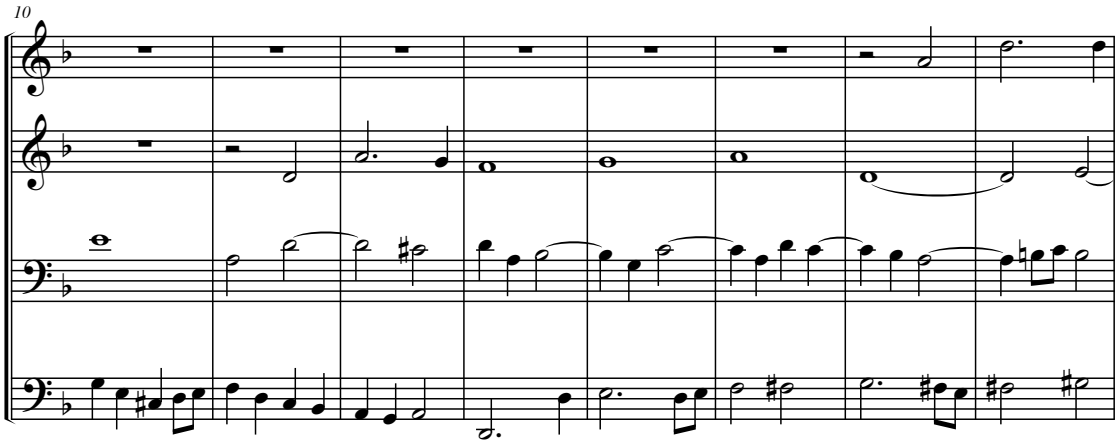


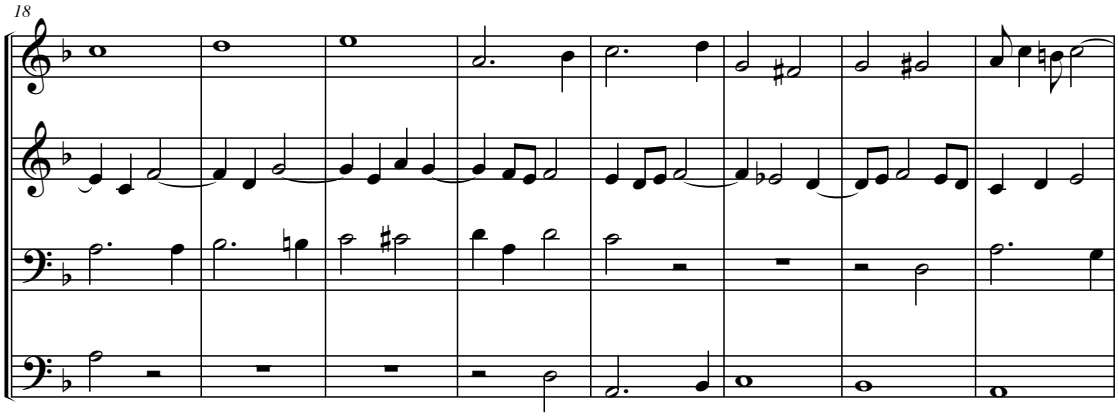
The completion of *Contrapunctus XIV* as presented here, follows the guidance set forth by Goncz's permutation matrix.

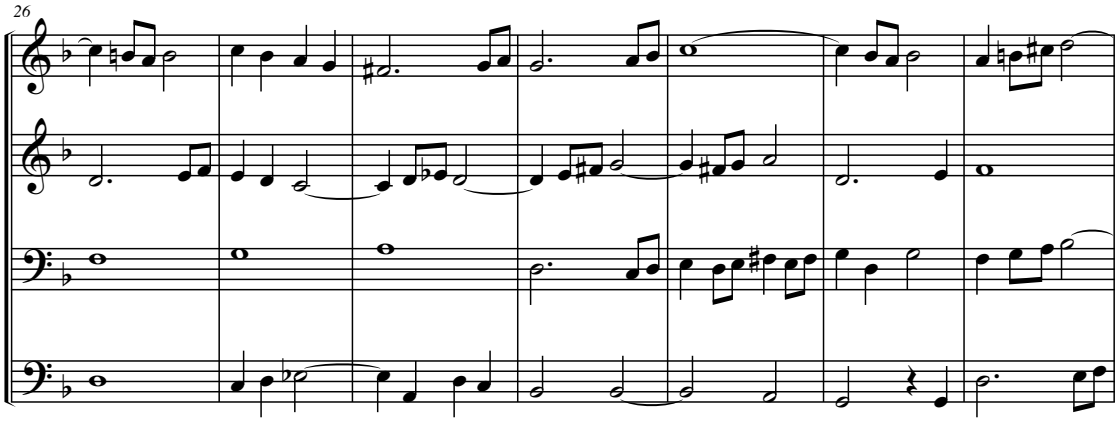
Contrapunctus XIV Completion
(from The Art of Fugue)

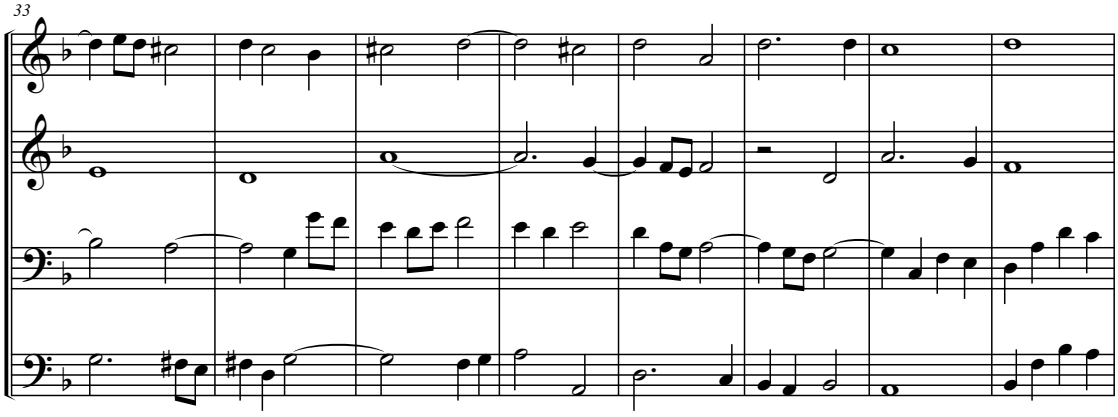
J.S. Bach
Completed by Bian Hansen

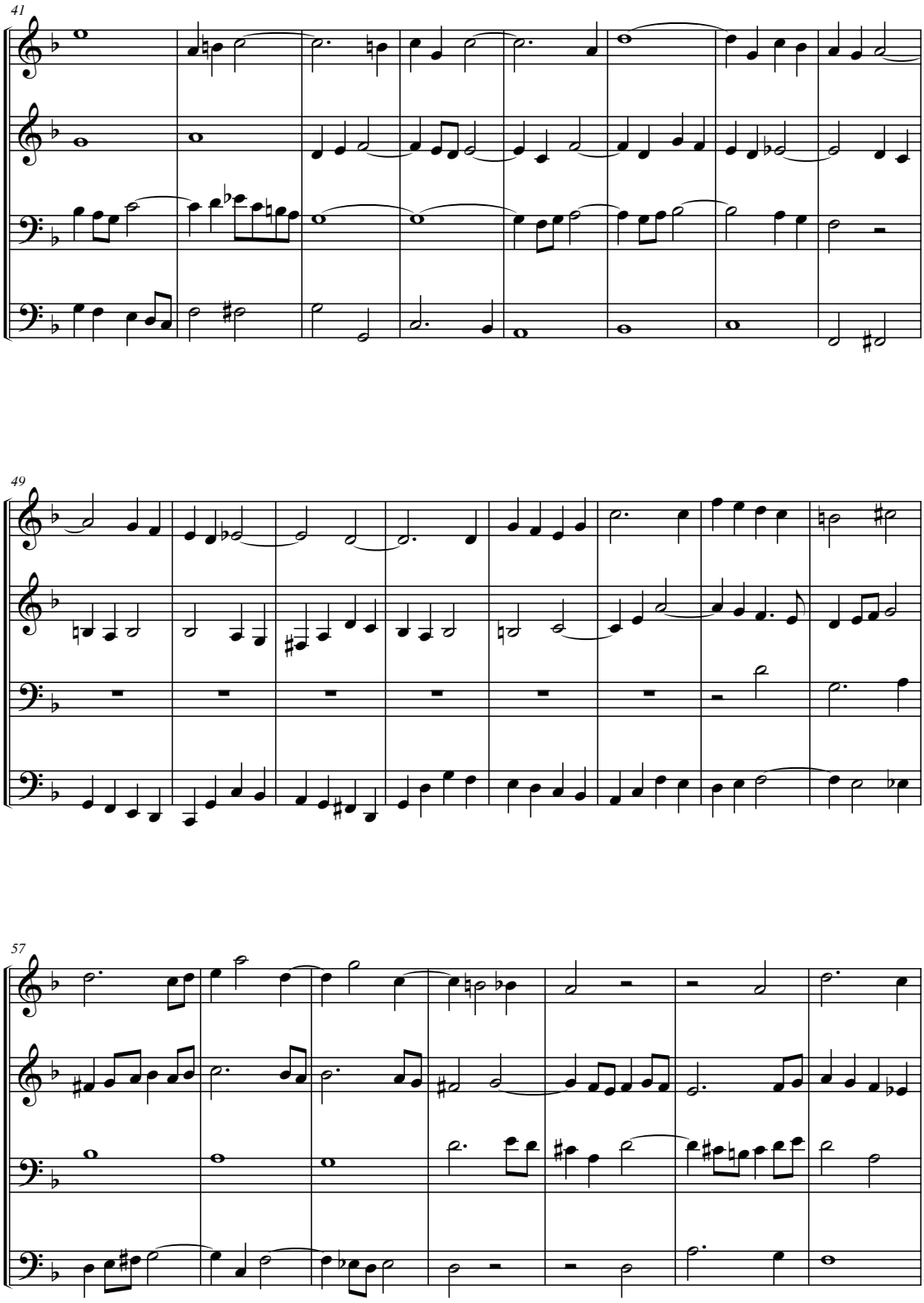


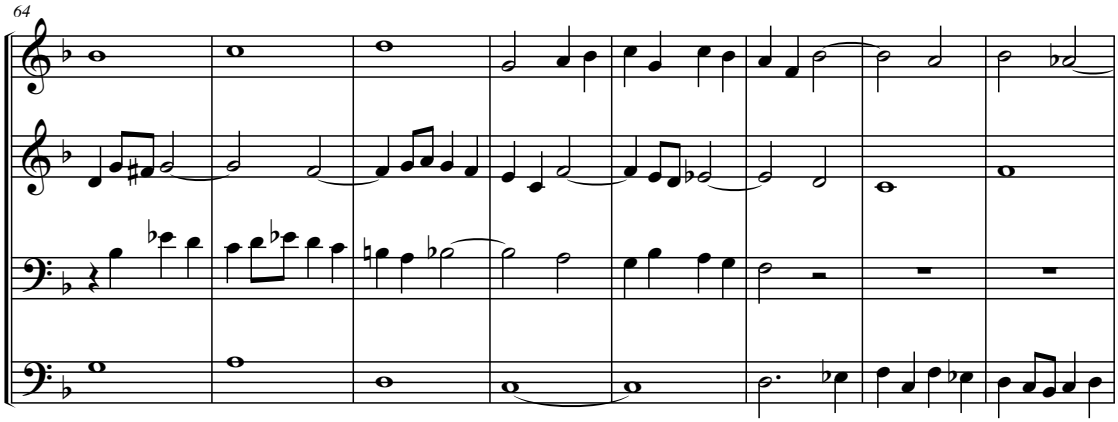


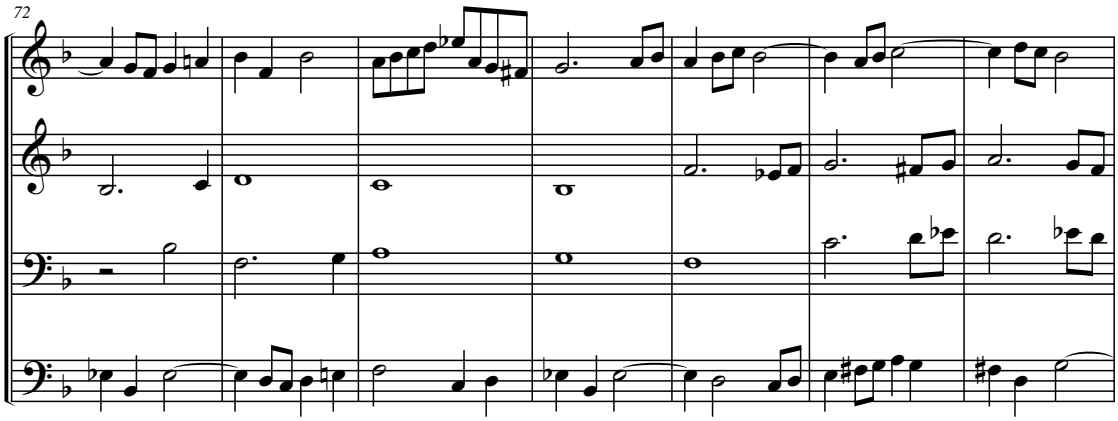

18

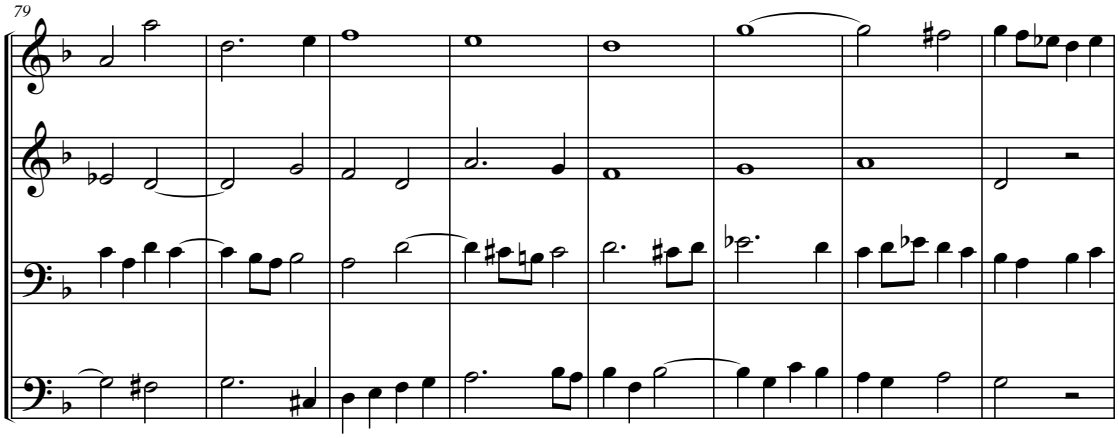

26

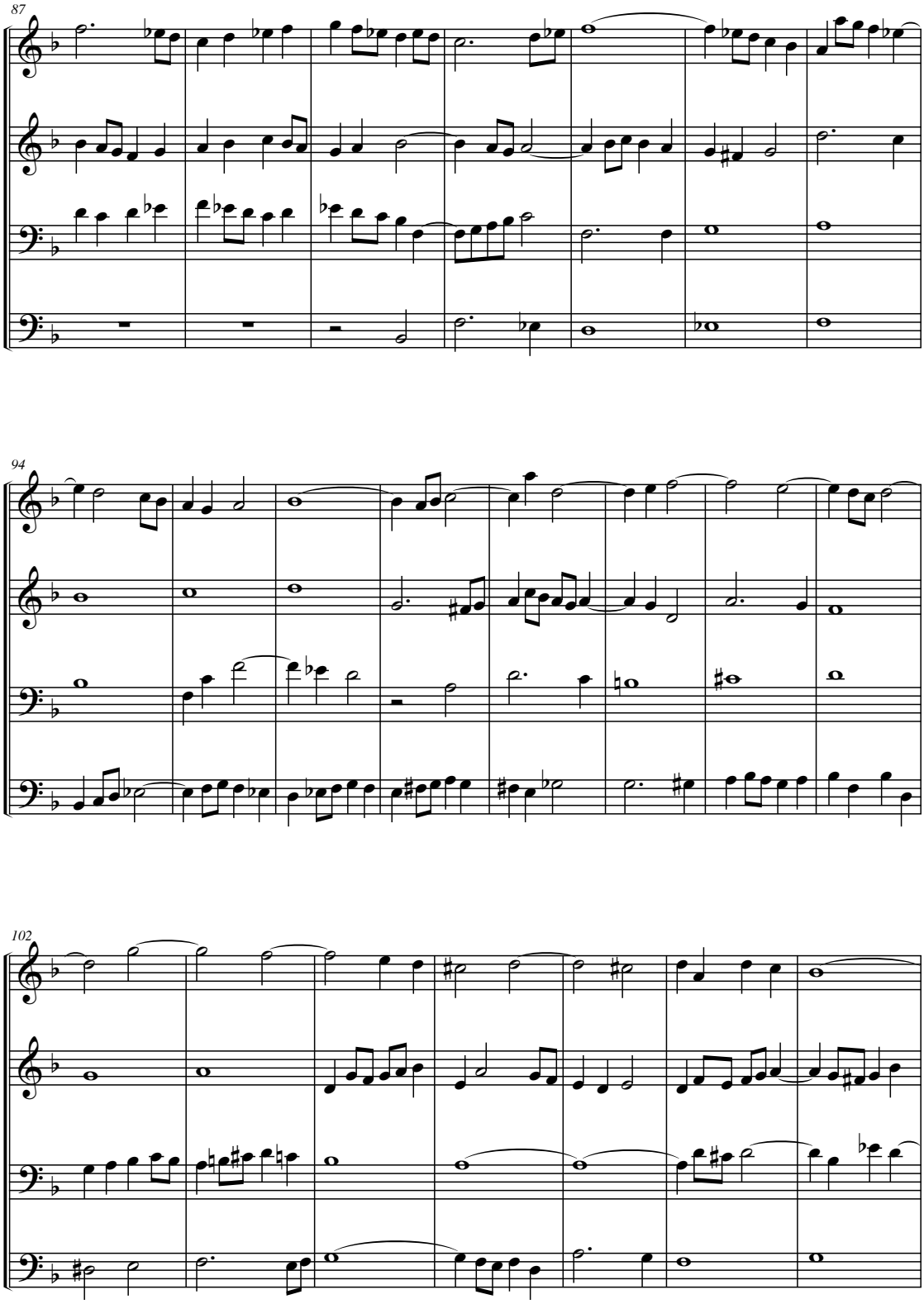

33

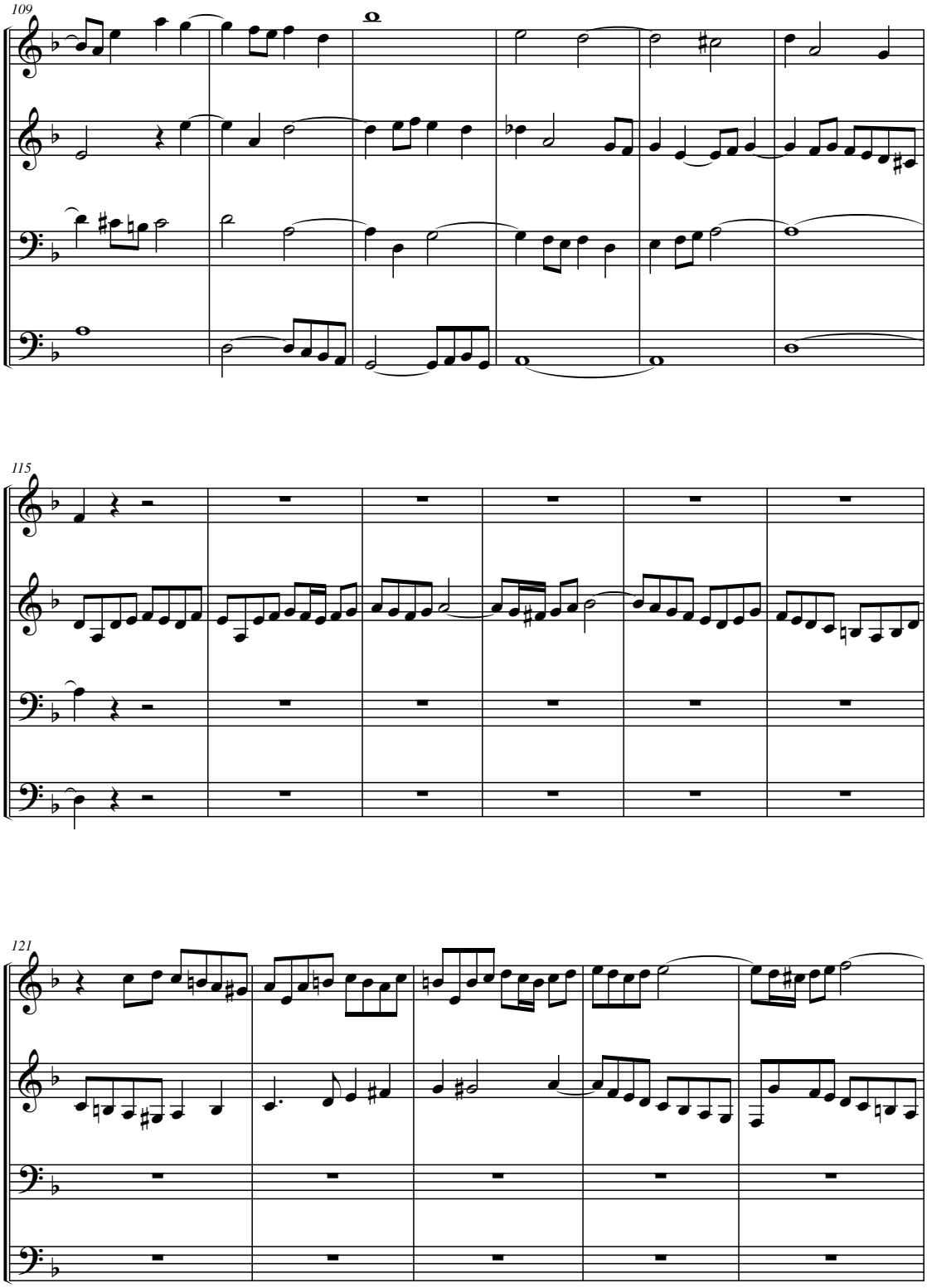

41
49
57

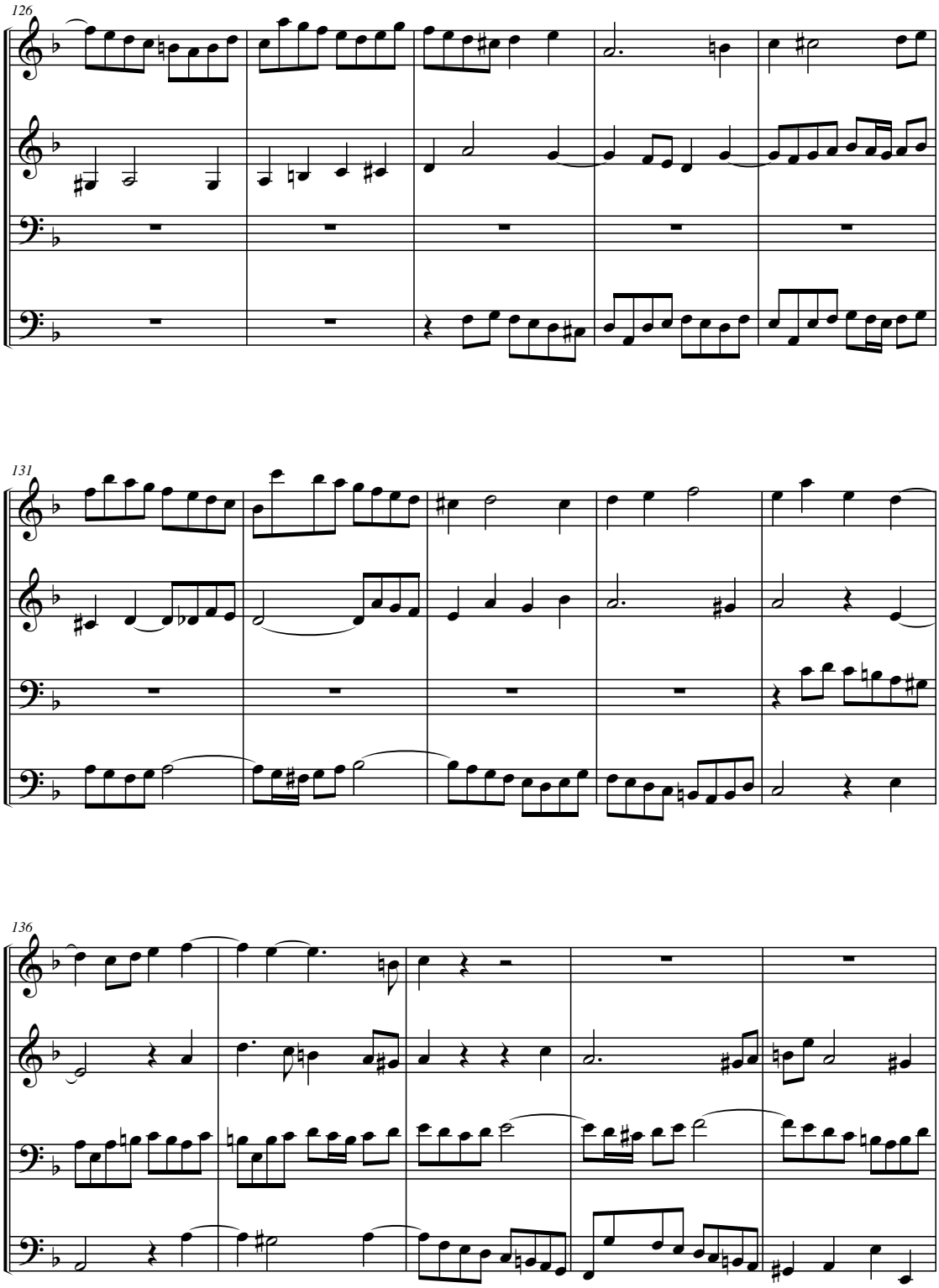

64

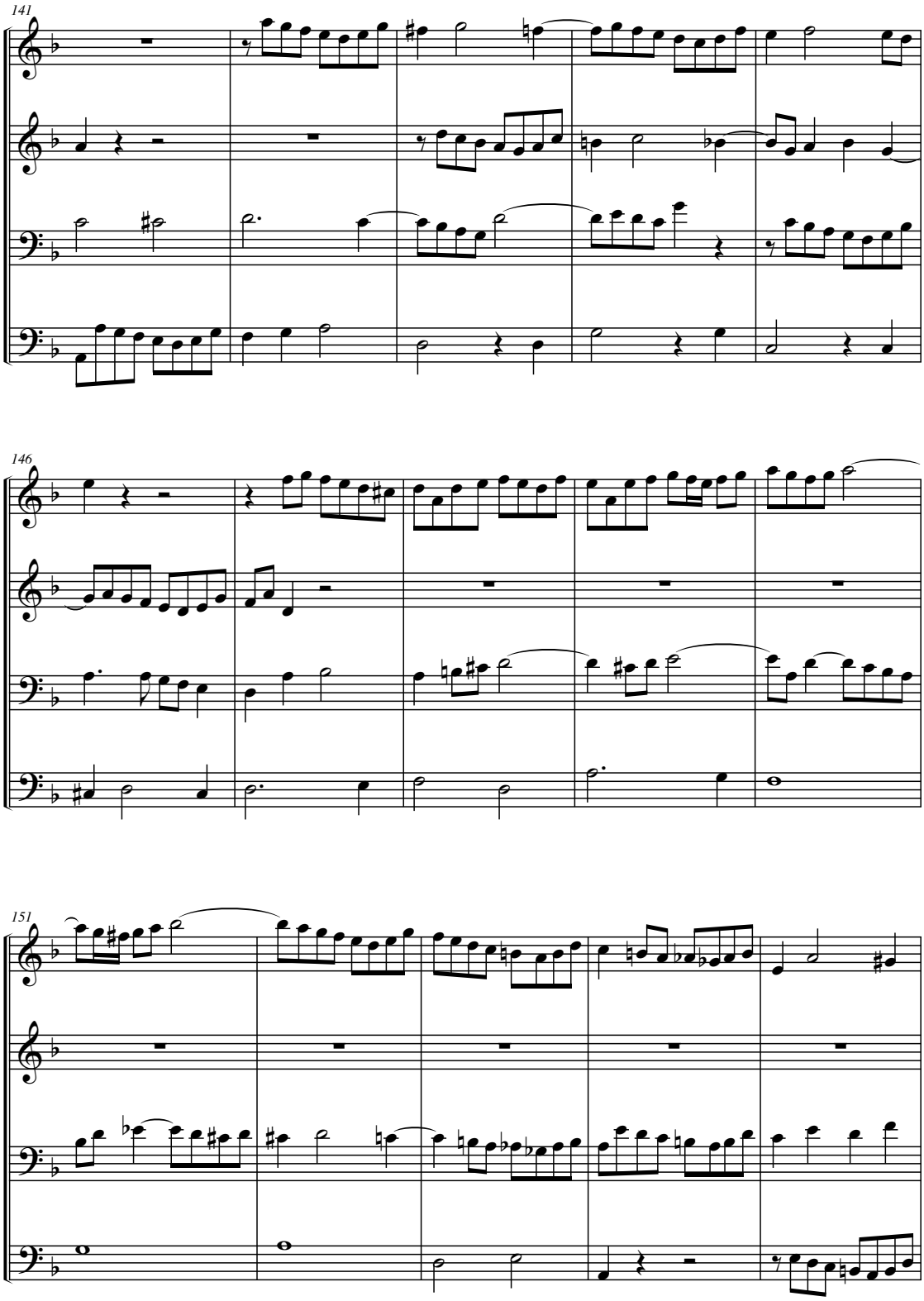

72

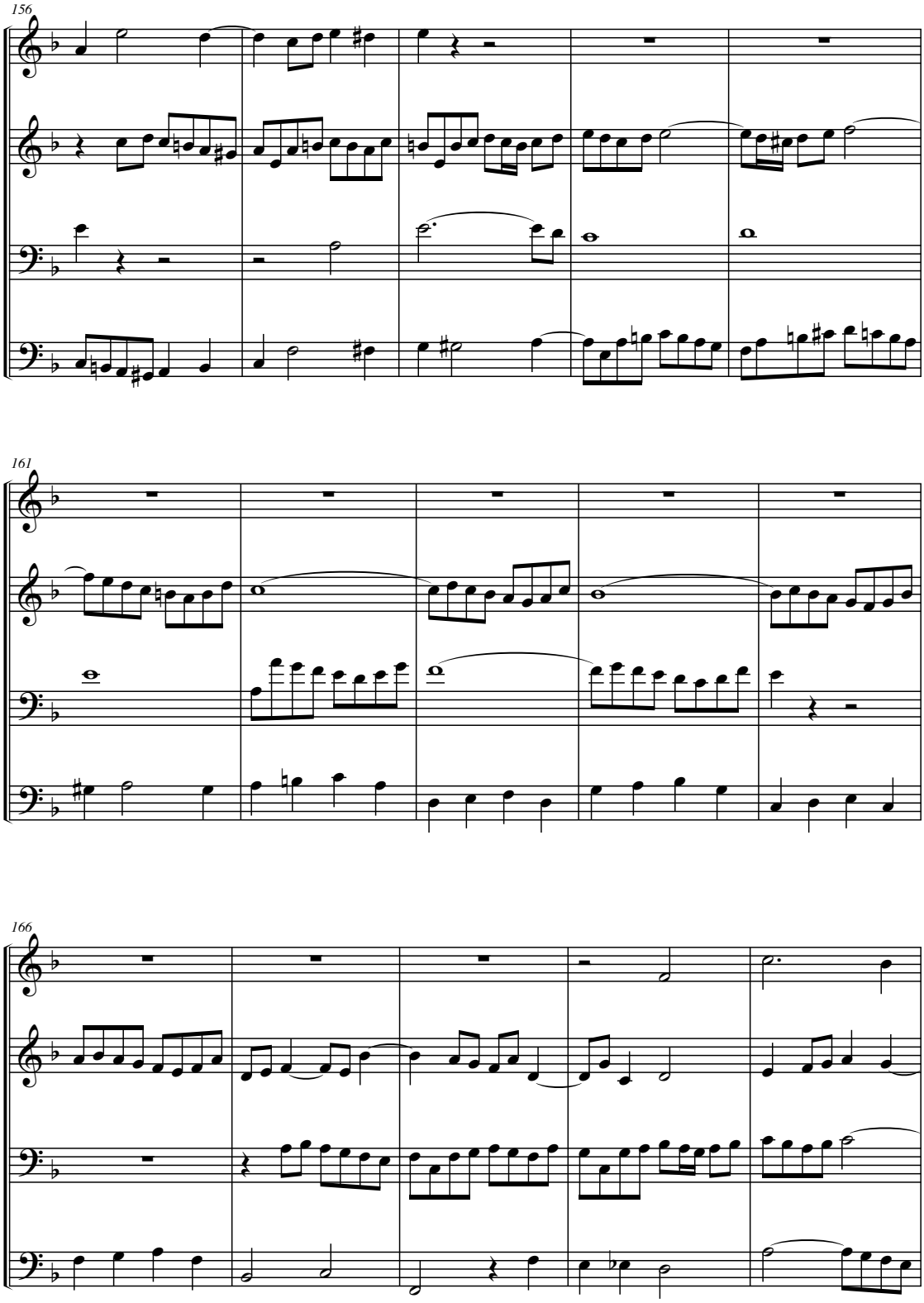

79

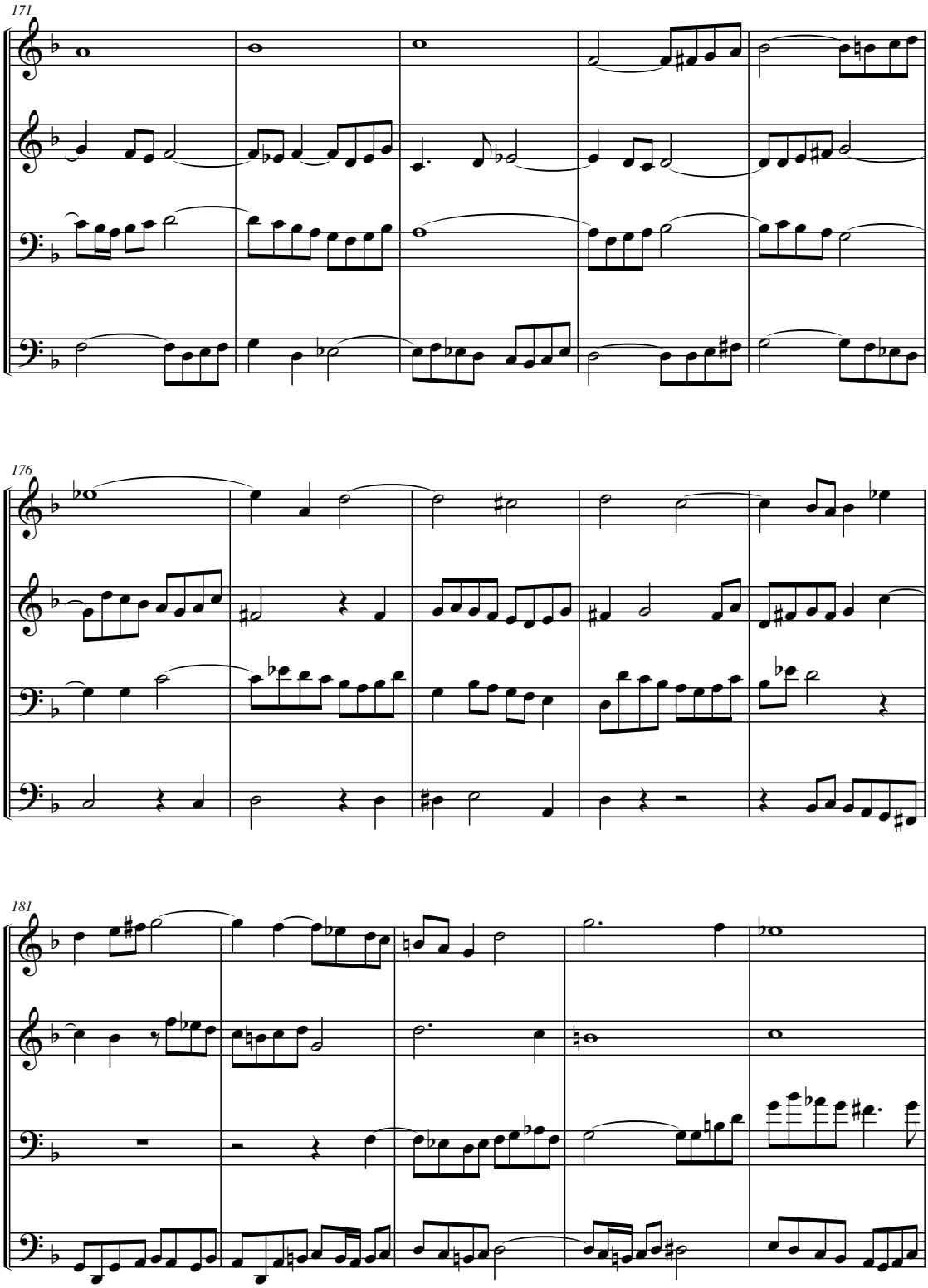

87
94
102

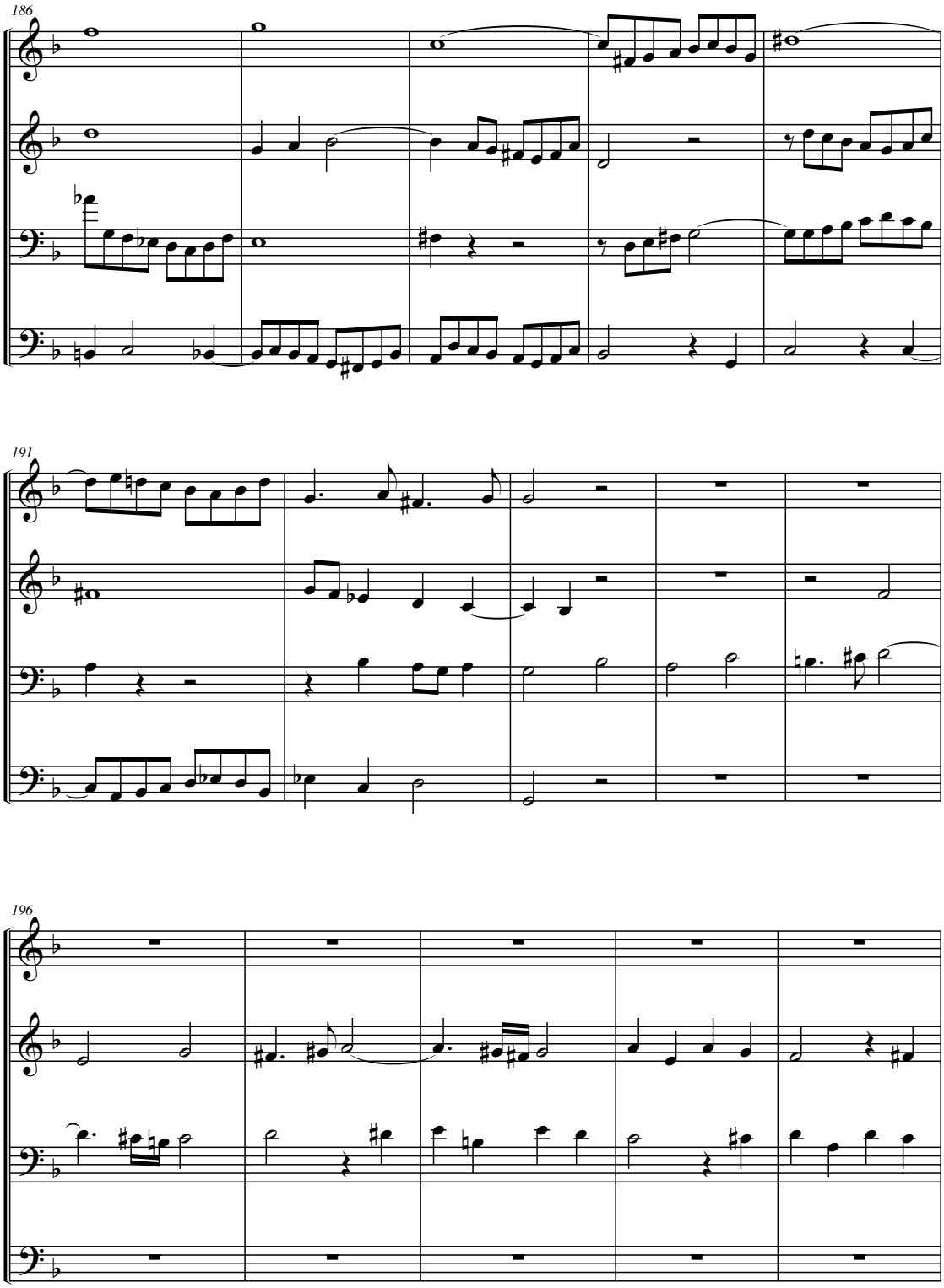

109
115
121

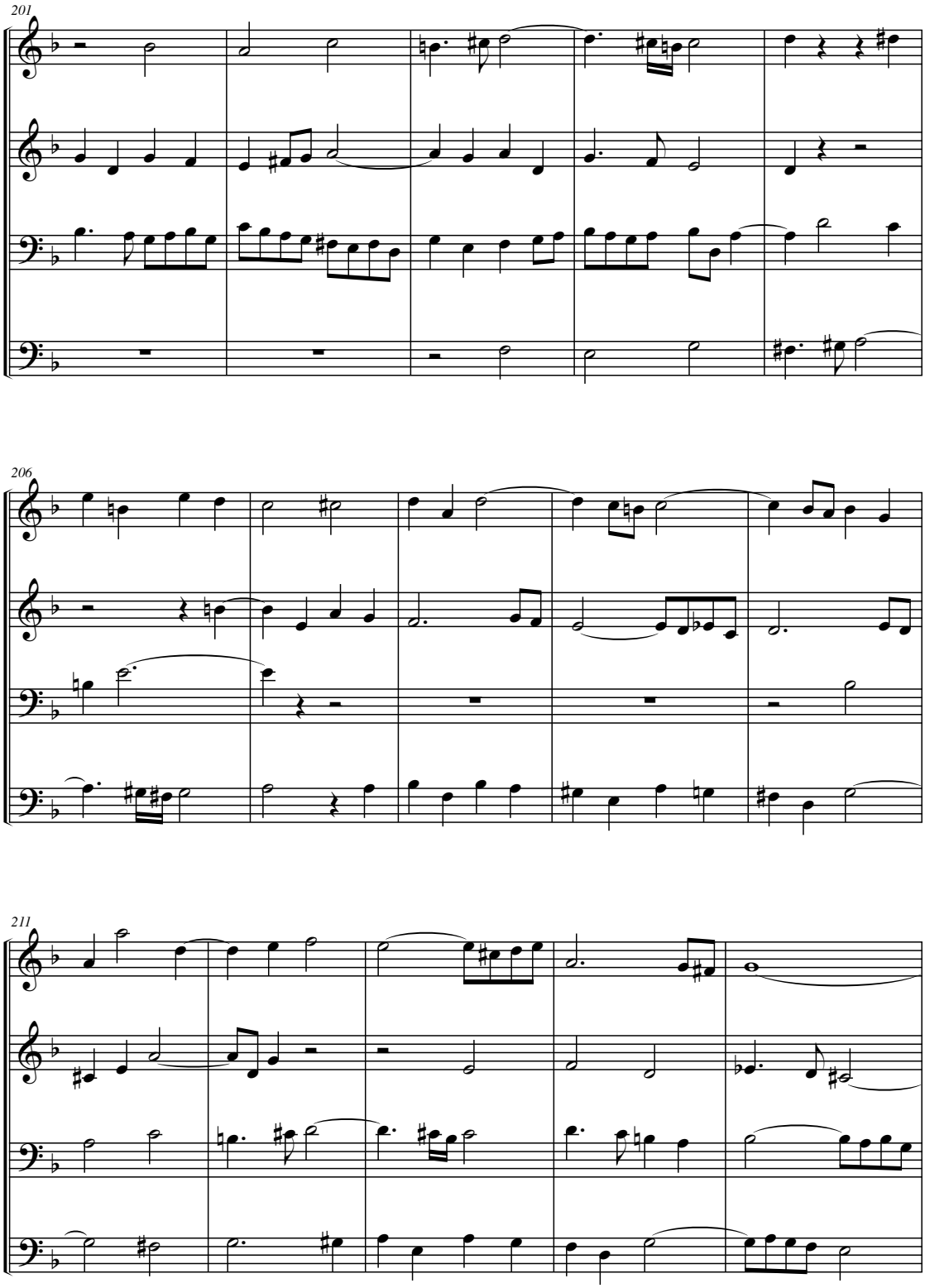

126
131
136

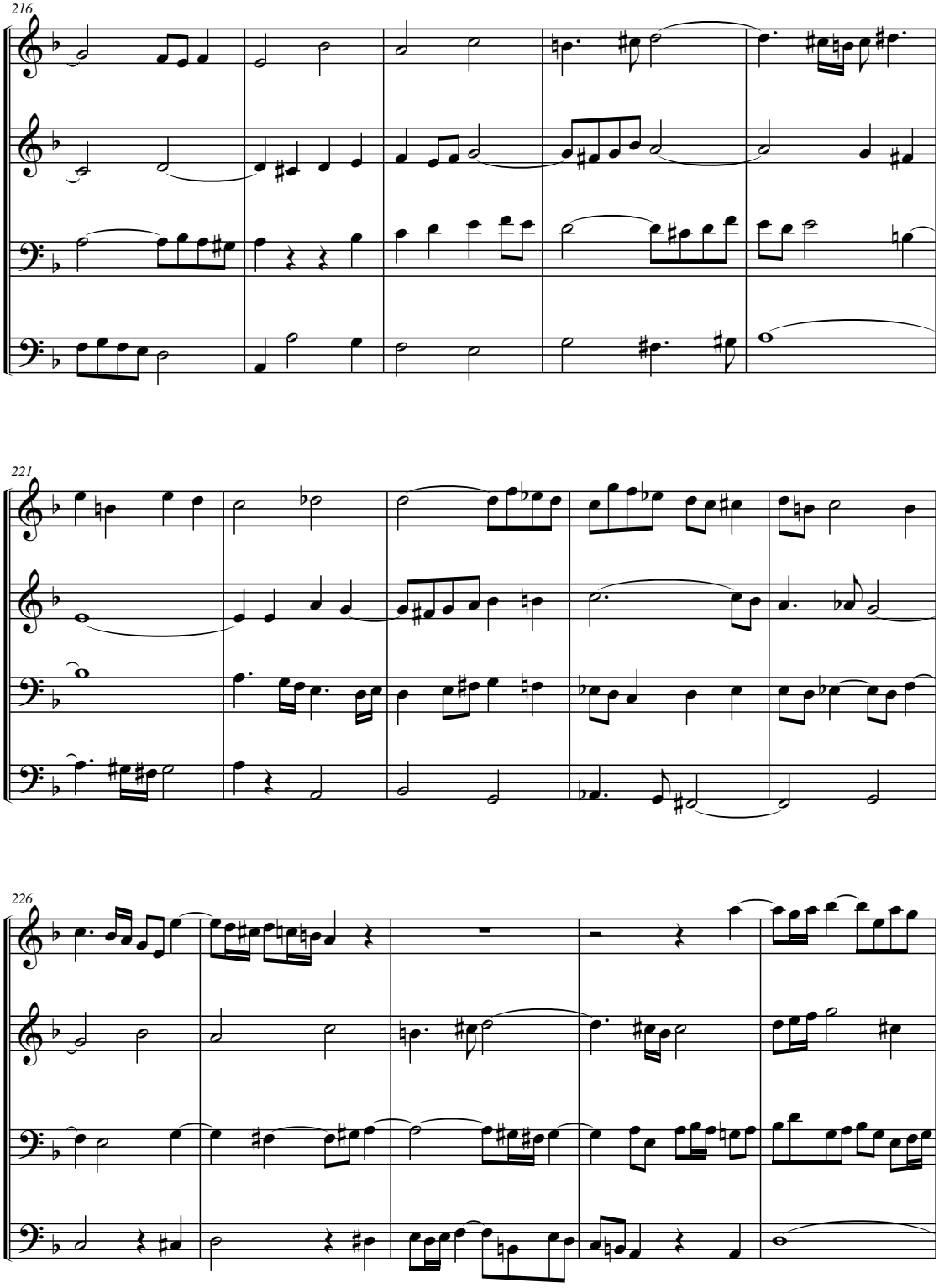

141
146
151

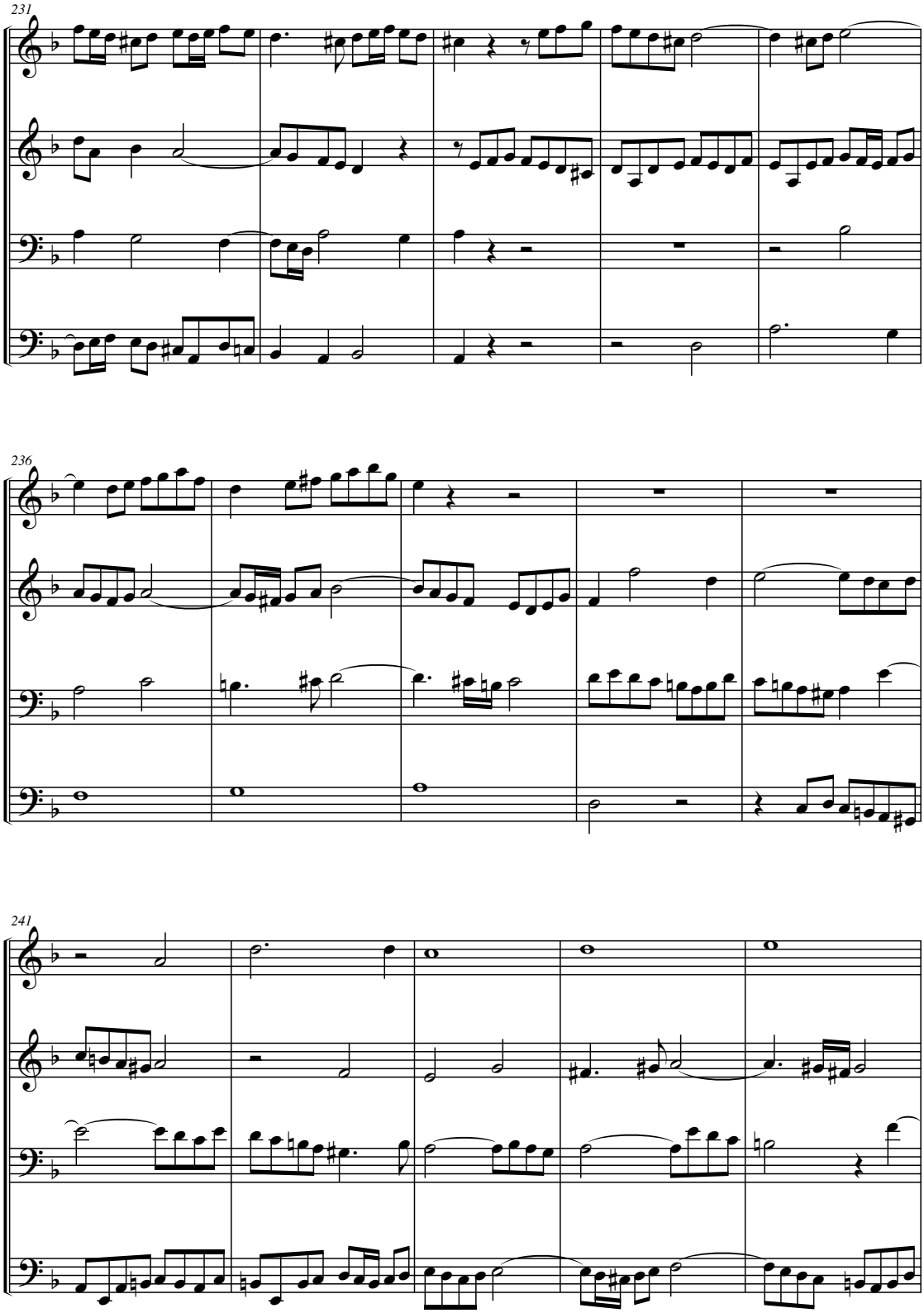

156
161
166

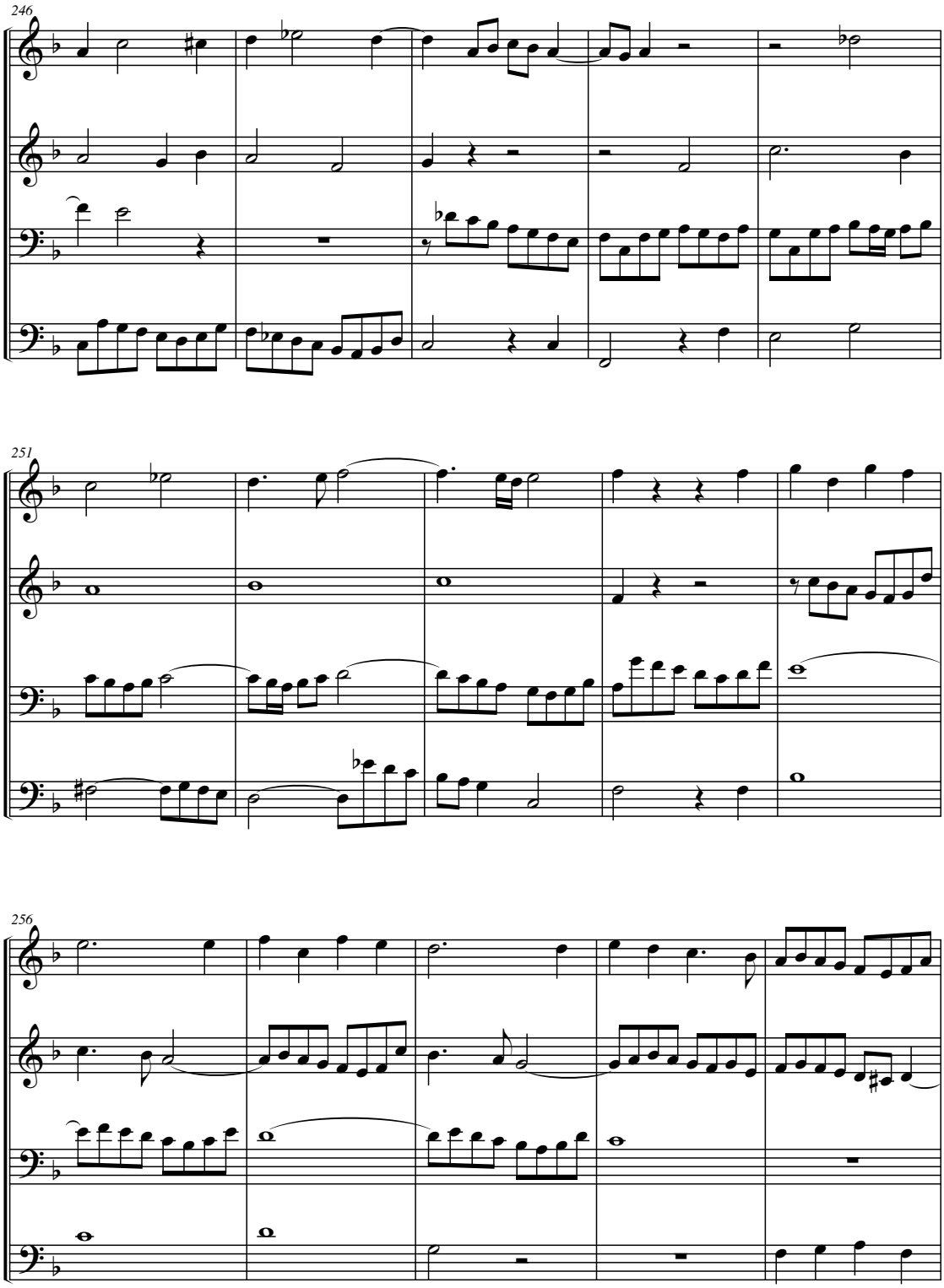

171
176
181

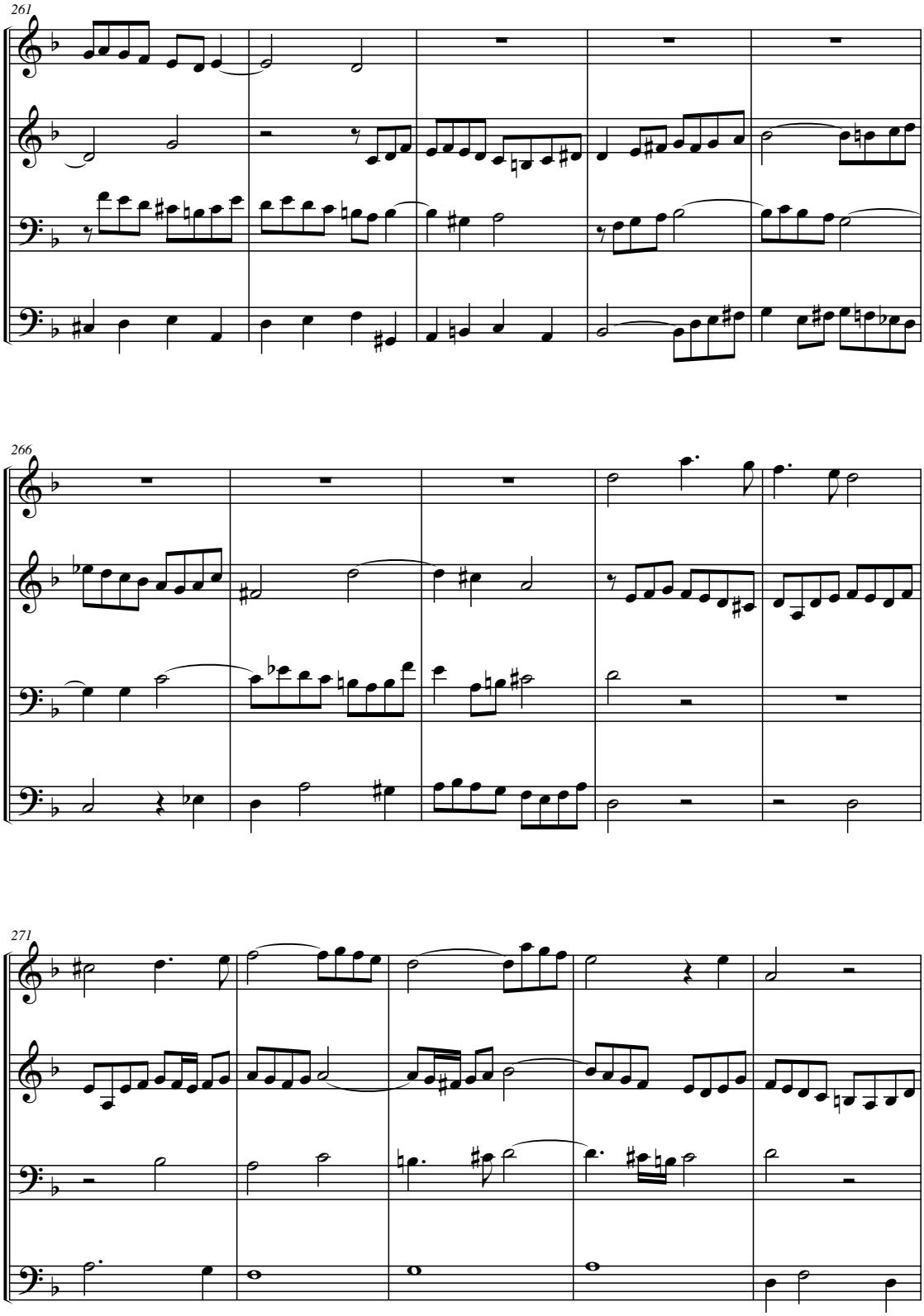

186
191
196

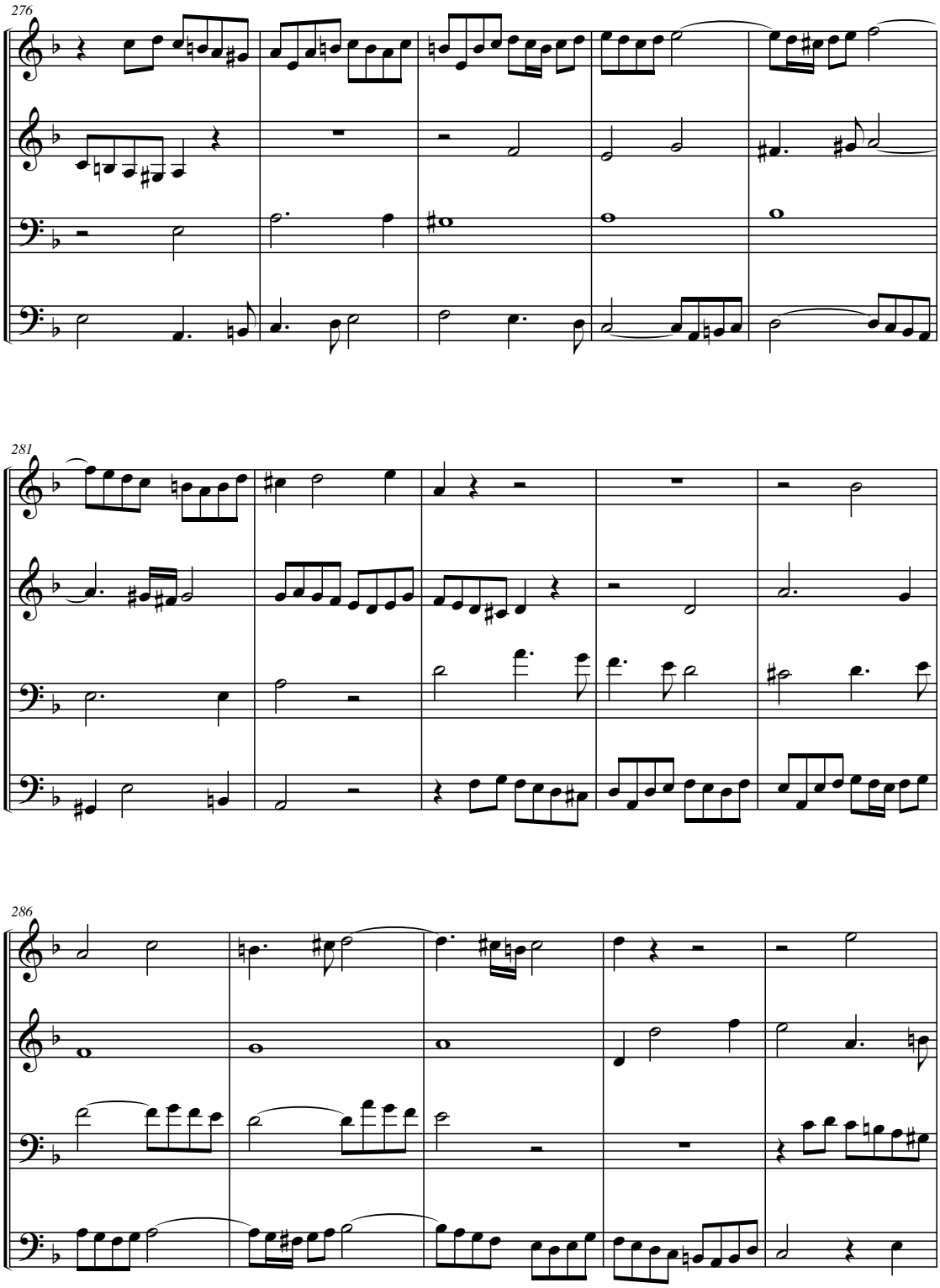

201
206
211

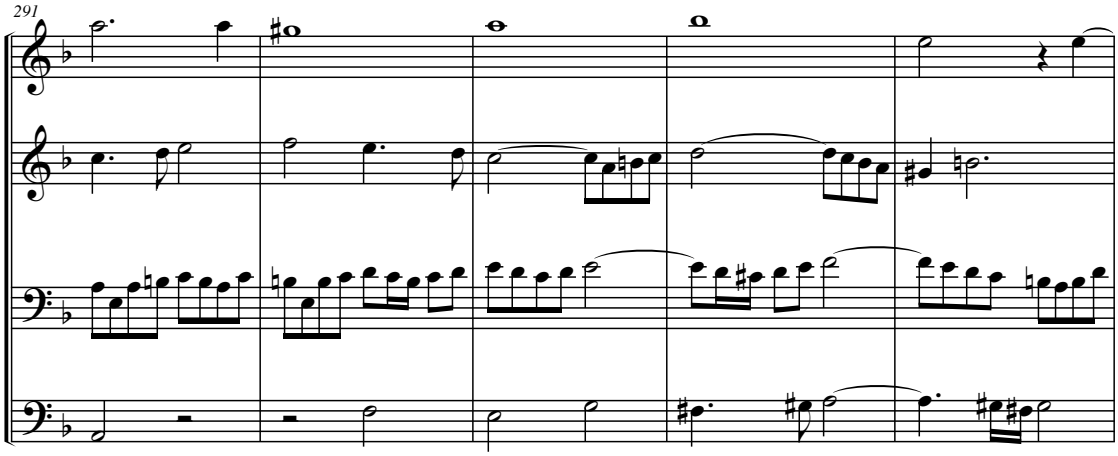

216
221
226

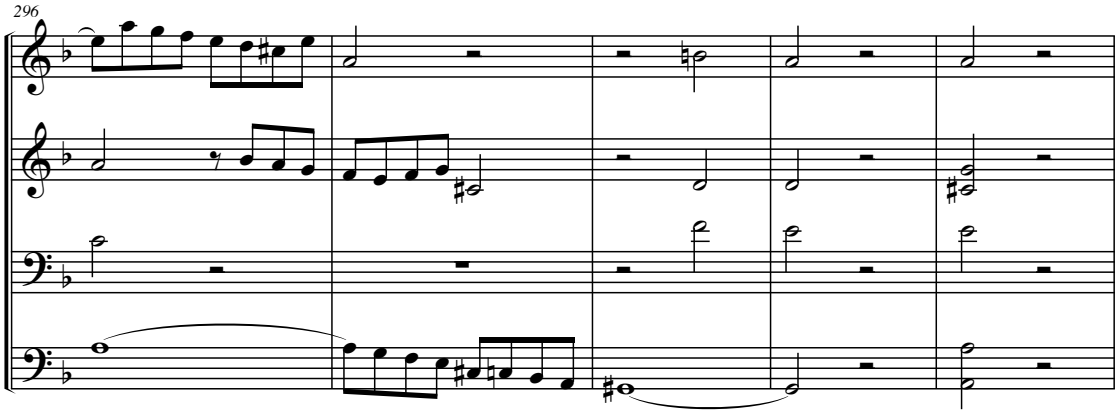

231
236
241

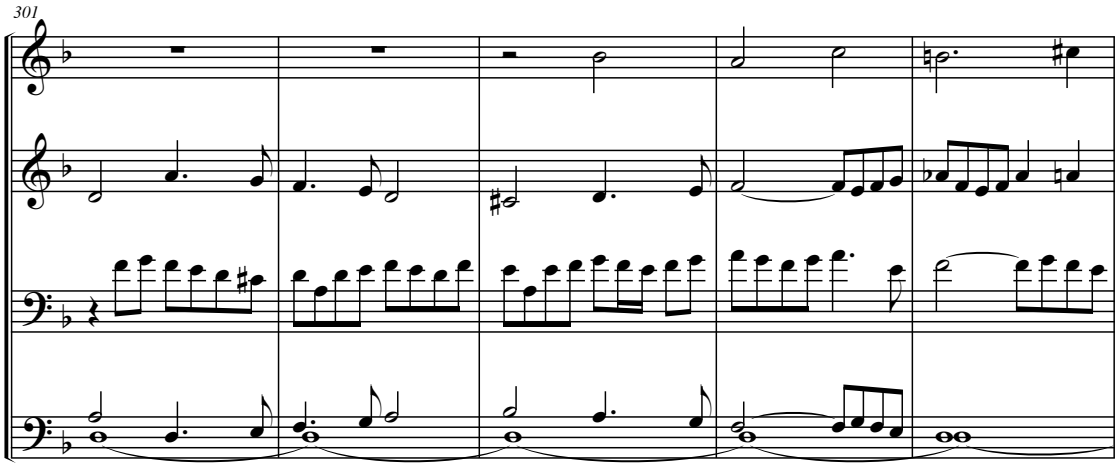

246
251
256

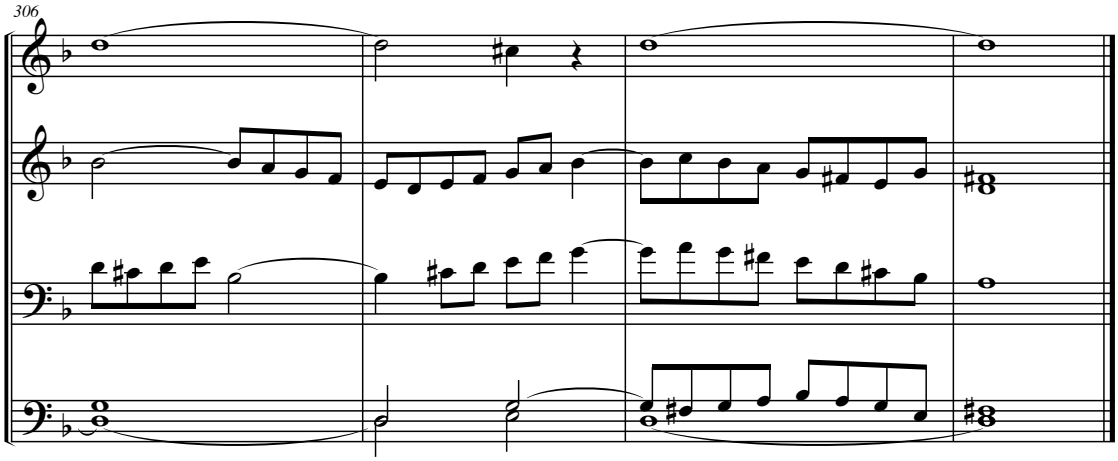

261
266
271


276
281
286


291


296


301


306

VI.

San Viento

for fixed electronics

San Viento CD 2 Track 1 (8’57”)

The piece *San Viento* (Wind Saint) is a reference to an experience I had while visiting San Diego. I happened upon a shop that was a distributor of wind chimes. This shop was primarily open air, which allowed currents of wind to travel through it and excite the different groups of chimes. A multitude of attacks, timbral hues, and harmonic clusters in a plurality of tunings collided and morphed with each other from different locations throughout the store. The resulting sonic environment was captivating, and this piece is an attempt to regenerate it.

Upon hearing enough groups of chimes, we are left with an overall impression. This impression, in a somewhat Aristotelian way, alludes to form. We understand and are able to deconstruct the foundational elements present in the sound of the chime cluster, that of attack and sustain. The deconstruction is then reconstructed into spectral sustains and grossly exaggerated attack clusters, as the piece moves towards its finale.

VII.

A Family Portrait

for fixed electronics

A Family Portrait:

- *Father* CD 2 Track 2 (2’02”)
- *Mother* CD 2 Track 3 (1’34”)
- *Son* CD 2 Track 4 (1’41”)
- *Daughter* CD 2 Track 5 (2’02”)

A Family Portrait consists of four pieces, where each piece is a sonic snapshot of a family member. Each piece is to depict an impression of the person’s identity. This is not accomplished by the individual speaking of past experiences or expressing their point of view. Rather, the spoken content and its context are destroyed and rearranged such that the locution of the speaker becomes the focus. Essentially, it is not the story that matters, but how one tells it which formulates the impression of character and identity.

VIII.

Drops: Popping Drains and Lapping Waves

for fixed electronics

Drops: Popping Drains and Lapping Waves CD 2 Track 6 (5’10”)

This composition, in the style of musique concrete, utilizes the sounds of water. Single drops of water become transposed and clustered to form sonic clouds. The gurgling and popping of water going down a drain, the gentle lapping of waves on a lakeshore, and the sound of splashes from stones thrown into a pool are all present and arranged in the sonic collage.

IX.

sinophonme

for fixed electronics

sinohponme CD 2 Track 7 (4’20”)

This composition is constructed from pure sine tones via additive synthesis. The structure of the piece is rooted in the theory of developing scales from dissonance curves as presented in William Sethares’ *Tuning, Timbre, Spectrum, Scale*. According to the theory, a unique scale can be devised from the unique timbre of a given pitch. In *sinophonme,* the spectral makeup of a given tone yields a dissonance curve such that the most consonant scale tones occur at ratios of 1.155, 1.316, 1.520, and 1.731 against the fundamental. The uniqueness of this scale and resulting intervallic relationships of consonance and dissonance are presented in the piece.

X.

Arch

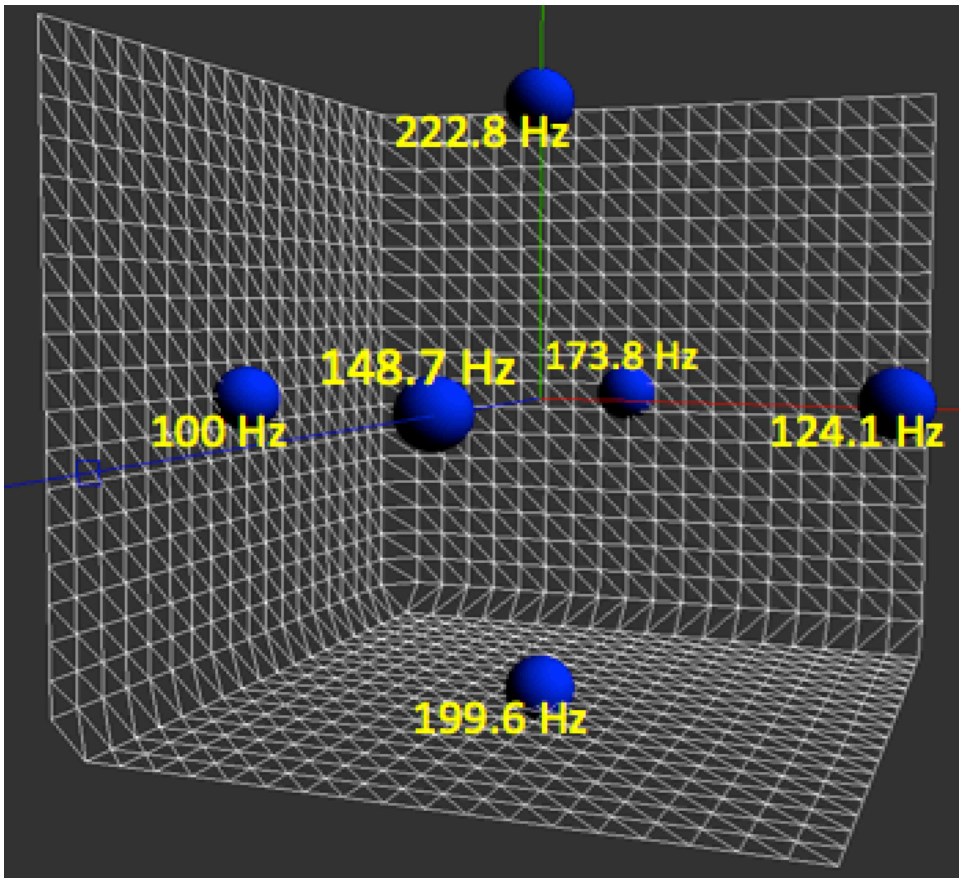
a virtual sonic sculpture

DVD

Arch is a virtual sonic sculpture. The sound is “sculpted” in an environment by spatializing sound sources such that unique levels of sensory dissonance occur in different areas of the space. The listener then experiences the sound sculpture via hearing different amounts of roughness in different areas. The sculpture can be visualized using the technique of isosurfacing. In the case of *Arch*, a 3D model with sonic accompaniment allows us to navigate the sonic sculpture and experience it through sound with the visual guide of isosurfacing.

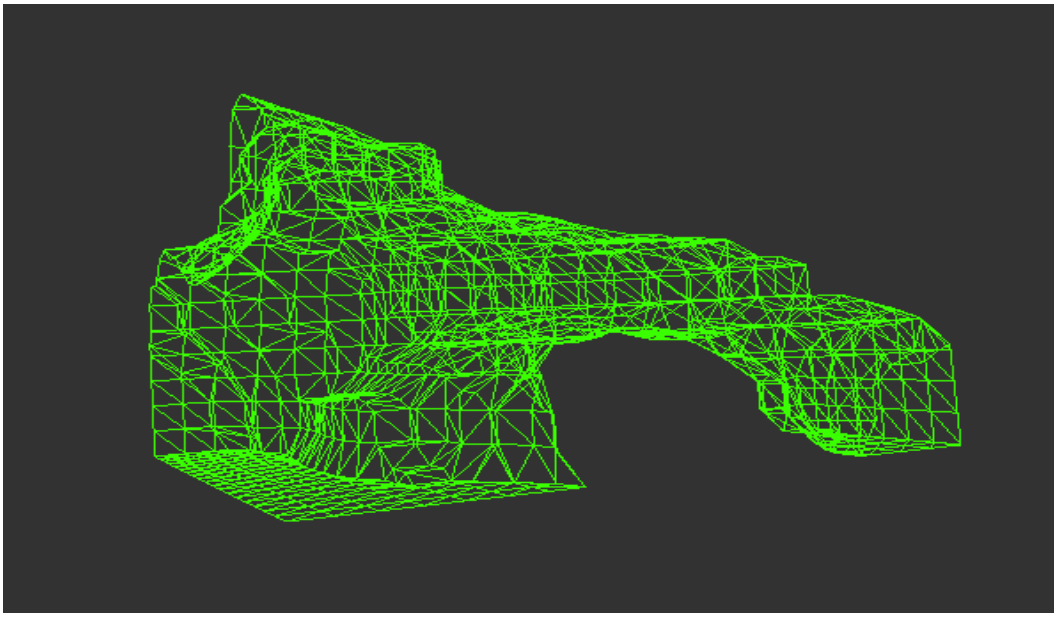
Arch was constructed with six sound sources, where each sound source is placed in the center of one of the six sides constituting the border of a cubic space. Each sound source emanates a sine tone, and each tone is separated in frequency by 0.25 barks (the point of maximum roughness in a given critical band). The figure below illustrates the setup.

Figure 10. Placement of the sound sources for *Arch*



The placement of the sound sources allows for the maximum amount of sonic roughness to be experiences in the center of the cubic space. The converging tones produce an arch like dissonance field as visualized by the isosurfacing image below.

Figure 11. The dissonance field producing the *Arch* sculpture



XI.

Sensations of Tone

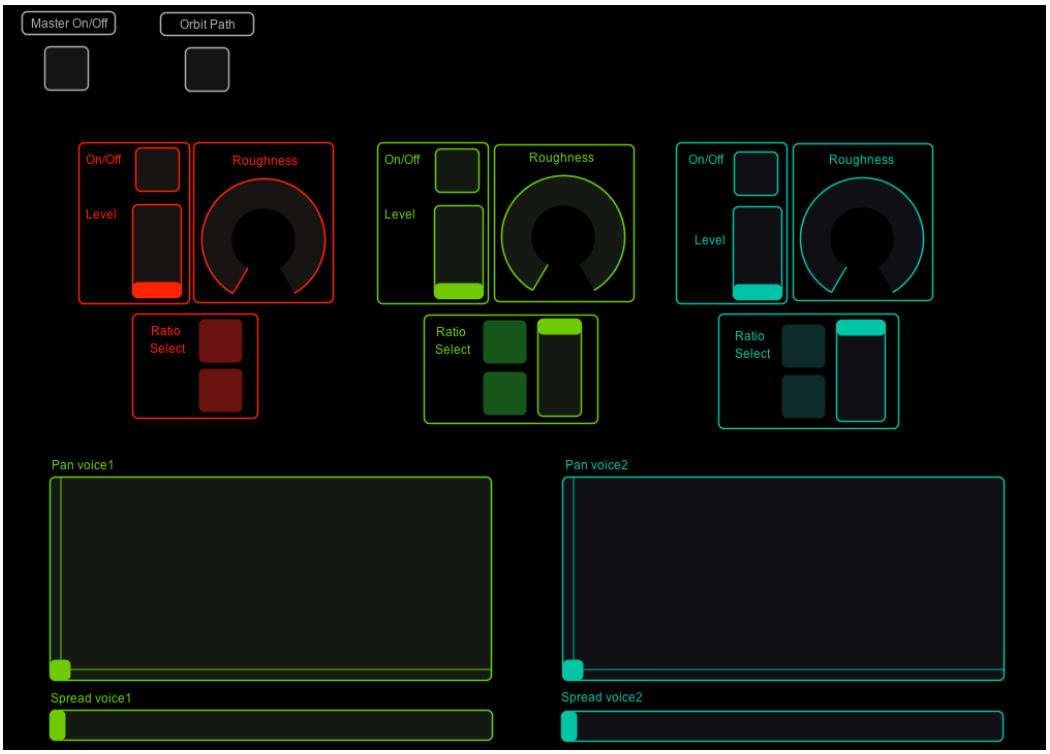
an interactive audio-visual installation

DVD

Sensations of Tone is an audio-visual piece set up for the Allosphere in the California NanoSystems Institute (CNSI) building at the University of California Santa Barbara. The piece is an interactive installation that allows users to create sonic environments via exploring various levels of sonic roughness. The piece has its core lying in the theories associated with sensory dissonance. In particular, algorithms are employed that allow the user to control the amount of roughness present in a given sonic spectra and that allow the user to select optimum combinations of the spectra.

There are three voices that can be generated: a bass and two upper voices. The user may control the sonic atmosphere by adjusting volume, roughness level, pitch ratio, and panning fore each voice. This is accomplished with the iPad interface displayed in the figure below:

Figure 12. interface for controlling parameters of *Sensations of Tone*



The interface communicates with a MaxMSP patch, which acts as the control center for the audio environment and graphics production. It displays the volume and roughness levels of each voice. In addition, it displays the dissonance curve relationships between each upper voice and the bass. Finally, optimal tuning ratios and the currently selected ratio are displayed for each upper voice.

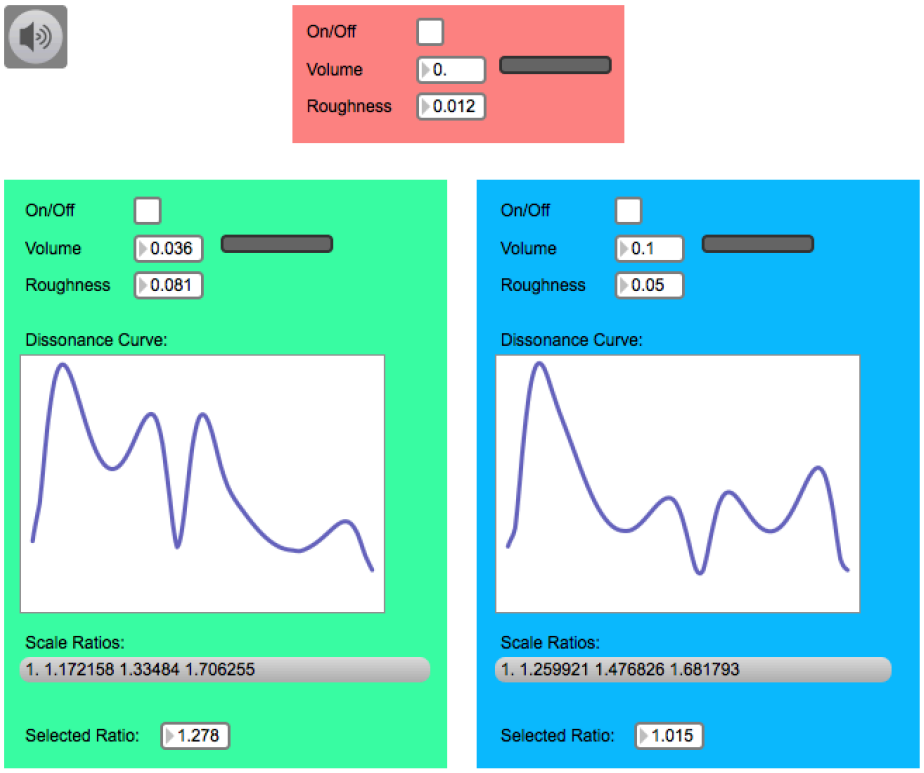



Figure 13. Main control center for *Sensations of Tone*