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El Árbol de la noche triste, for solo viola with live electronics

by

John Andrew MacCallum

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

in

Music Composition

in the

GRADUATE DIVISION
of the
UNIVERSITY OF CALIFORNIA, BERKELEY

Committee in charge:
Professor Edmund Campion, Chair
Professor David Wessel
Professor David Milnes

Fall 2010

El Árbol de la noche triste, for solo viola with live electronics

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by

John Andrew MacCallum

For Kate.

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Acknowledgments

First and foremost, I must thank Ellen Ruth Rose for whom *El Árbol* was written and to whom it is dedicated. Her willingness and enthusiasm to experiment with her instrument are unmatched and were a great source of inspiration while working on this piece.

I also must thank those members of the Music Faculty at UC Berkeley who have nurtured and mentored me during my time here. I could not have asked for a more supportive group of advisors and will remain indebted to them long after I leave. In particular, Edmund Campion has provided me with a great deal of advice and insight, musically, professionally, and personally; the encouragement of Cindy Cox to remain focused on composing has helped me to stay on track and keep my goals in sight; David Milnes, consummate champion of new music, set the bar high and challenged me to raise myself to it; and in David Wessel, in many ways my mentor and hero, I have found inspiration through his unparalleled breadth of knowledge of all things musical and gastronomic.

I also wish to acknowledge Adrian Freed with whom I have worked closely during my time at CNMAT both as a graduate student and staff member. Being in close contact with an individual with such curiosity about the world around him and such an immense knowledge about it has been inspiring beyond words.

A number of friends and colleagues also deserve mention here, in particular, Andy Schmeder who has been my colleague at CNMAT for a number of years has always been generous with his time and willing to share his thoughts and ideas about any topic. I hope the many barbecues have been repayment enough. Also, Aaron Einbond and David Coll with whom I have had endless debates on all things musical, aesthetic, and technical. So

many of my ideas about music have resulted from discussions with them over an immeasurable volume of beer that I almost feel that their names should be on the score alongside mine. However, that may not be desirable to them. I would also like to acknowledge Michael Zbyszyński and Matt Wright, two colleagues of mine from CNMAT who have since moved on. The shoes they left behind at CNMAT are enormous.

I cannot say enough about the support and encouragement I have received from Kate. She has been wavering in her commitment to myself and my goals. It is hard to imagine that I deserve the kindness she has shown me.

Finally, no words of thanks are profound enough to match the generosity and support my family has shown me.

Abstract

El Árbol de la noche triste, for solo viola with live electronics

by

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El Árbol de la noche triste is a composition for solo *scordatura* viola and electronic sounds which are generated algorithmically in real-time during the performance. In the work that follows, the compositional techniques employed throughout the piece are discussed along with the design of the algorithms used in the computer part. The retuning of the viola to four partials of a harmonic series in the manner described below severely constrains the compositional possibilities, but also creates a number of affordances that are not present on the traditionally tuned instrument. One is forced, when working within such constrained environments, to design compositional systems that take into account the nature of the instruments for which one is composing in a much more profound way than when composing for instruments in a configuration familiar to both the composer and performer. The compositional system becomes inextricably linked to the medium; one composes for the instrument instead of in the abstract.

A similar approach is taken with the computer: the compositional system has many features in common with that of the viola, but is only realizable on the computer. The result is the unification of the antithetical worlds of the acoustic instrument and the computer through compositional process.

Chapter 1

Introduction

Two striking features of *El Árbol de la noche triste* warrant discussion here: the *scordatura* of the viola and the algorithmic nature of the electronics. We present some basic ideas pertaining to the compositional issues surrounding these features of the work before proceeding to a more thorough technical discussion of the composition in chapter 2.

1.1 Writer's Block

The image of a writer, painter, or composer sitting in front of a blank piece of paper, canvas, or score paper unable to write, paint, or compose given the infinite possibilities implied by the blinding white blankness is a familiar one. Once the continuum has been broken by even a single word, line, or note, the weight of infinite choice is lifted—there is now something in place that the artist must react to. As more elements are placed in opposition to those occupying the space, the infinitude of the blank canvas becomes all but forgotten.

As we choose the next word, phrase, color, shape, note, or chord, we make judgments about how well it fits with the surrounding material. A compositional system, whether formalized as in dodecaphonicism, serialism, stochasticism, etc., or intuitive, is essential to the compositional decision-making process. Indeed, if we are able to make even a single musical decision, even if we would describe such a decision as intuitive, we can be sure that there is a compositional system in place.

Often, these systems are abstract—they provide organization and structure to musical materials independent of the instrument on which they will ultimately be performed. At some point in the compositional process, earlier for some, later for others, the constraints and affordances¹ of the instrument(s) begin to affect the way in which the compositional system is deployed.

The act of ordering our basic musical material, whether using twelve-tone methods or concepts from group theory, draws out of the shadows hidden affordances latent in the basic material. For example, the linearly ascending chromatic scale in figure 1.1 and the twelve-tone row in figure 1.2 both contain the same set of affordances, however the two hexachords of the latter are, at the very least, not obvious in the former.



Figure 1.1: A chromatic scale.

The viola, tuned in the traditional fashion, like any other instruments presents a

¹A thorough discussion of the theory of affordances is unfortunately beyond the scope of this work. The reader is directed to [2] and [3] for two classic references from the literature.

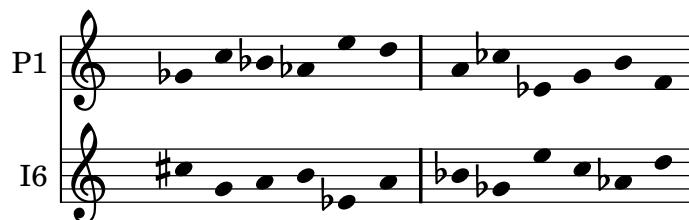


Figure 1.2: 12-tone row from the third of Schoenberg's *Three Songs*, Op. 48 (1933) segmented into two hexachords. [9]

set of constraints with which any composer and performer is intimately familiar. Retuning the viola as is done in *El Árbol* imposes additional constraints that are so severe that they demand their own compositional system. We are no longer composing for viola, but for *retuned* viola. Those constraints also give rise to affordances, some of which exist hidden on the traditionally tuned viola, and others that are unique to this new instrument. The result is a composition with an organization that is unique to the instrument for which it was written.

1.2 A Composition for Sewing Machine and Umbrella

Il est beau [...] comme la rencontre fortuite sur une table de dissection d'une machine à coudre et d'un parapluie! —comte de Lautréamont

The notion of electro-acoustic music, that is, music written for acoustic instrument(s) and electronic sounds is fundamentally problematic. The sounds of the former are inextricably linked to the gestures of the performer before us on stage, while the source of electronic sounds resides behind a familiar veil. We as listeners, at once occupy the role of *mathêmatikoi* and *akousmatikoi*, the learned and the auditors.²

²For a thorough discussion of these terms and their application to the rich history of electronic music, see the following sources: [1], [4], [5], [6], and [10].

The medium of electronic sounds heard in concert typically falls into one of three categories:

1. fixed, such as a sound file, cd, or tape,
2. real-time, as effects applied to or generated from the musical material of the performer,
3. or performed using a specially constructed instrument.

In the first case, all visual elements that may have gone into the production of the sound have been removed and we are left with only the auditory trace. For practitioners of acousmatic music, the involvement of a performer on stage forces the audience to focus with their eyes and not their ears and calls into question the disembodied nature of the electronic sounds.

The second case is an attempt to appropriate the instrument(s) as the source of the electronic sounds. Here, the existence of the electronic sounds is predicated upon the instrumental performance; the computer becomes an extension of the instrument(s). Any attempt at autonomy of the computer part, any attempt to allow the computer to break free from the performer, only serves to emphasize its disembodied nature.

The third case represents a further attempt to actualize the electronic sounds either by placing the computer operator onstage or furnishing a performer with an instrument that will directly control the computer. The scene that the former suggests is often more bureaucratic or lascivious in nature than performative. In the latter case, links between gestures made on instruments that are unfamiliar to the audience are often difficult to associate with the resultant sounds in the same way that would be done with a clarinet or cello. One would be right, however, to question how acutely we can visually verify that a given sound is the result of some performative action. Since the visual apparatus is

easily fooled [8], it may be the case that our willingness to associate gestures with actions performed on instruments with which we are acquainted is based in our familiarity with them and the sounds they produce. Perhaps as instrument design continues to forge ahead, this problem will be mitigated.

Before moving on, we must say a few words about content. A sound itself can carry with it information that points to its origin, often some action performed on an object. While a sound dissociated from its source can communicate a sense of disembodiment, a purely abstract sound can exist as such without calling into question how the sound was produced. It is abstract, synthetic, produced in a lab, and is in no way the result of a physical action that has been obfuscated.

The work that we will describe below makes use of live, algorithmically-generated electronic sounds which are meant, in the same manner as Iannis Xenakis' *Analogique A+B* and Karlheinz Stockhausen's *Gesang der Jünglinge*, to coexist with clearly performative actions in dialectic synthesis. The sounds are intentionally abstract and evolve as the composition unfolds allowing for autonomy on the part of the instrumentalist who is free to perform the piece unhindered by any technological constraints, as well as the electronic sounds which exist according to their own logic.

Chapter 2

El Árbol de la noche triste

<i>Trescientas rosas morenas</i>	Three hundred dark roses
<i>lleva tu pechera blanca.</i>	cover your white shirt.
<i>Tu sangre rezuma y huele</i>	Your blood oozes and reeks
<i>alrededor de tu faja.</i>	around your sash.
<i>Pero yo ya no soy yo</i>	But I am no longer I,
<i>Ni mi casa es ya mi casa.</i>	nor is my house any longer my house.
—Federico García Lorca, <i>Romance sonámbulo</i> (excerpt)	

Ahora todo está por el suelo, perdido, que no hay cosa.
 Now all is in the dust, lost, there is nothing left.
 —Bernal Díaz del Castillo, after the massacre at Tenochtitlán

El Árbol de la noche triste is a composition for solo unamplified viola and live electronics lasting approximately 10–12 minutes. It was written for and is dedicated to Ellen Ruth Rose who premiered the work at the Mondavi Center in Davis California in January, 2010.

In this chapter, we will present a brief overview of the composition followed by a general discussion of the pitch material.

2.1 Overview

2.1.1 Instrumental Writing

The bottom three strings of the viola are retuned for this composition to the fifth, seventh, and eleventh partials of a harmonic series with a fundamental frequency of 27.5 Hz (the low A of the piano). This fundamental was chosen so that the A string would be the 16th partial and would not have to be retuned. Additionally, the work makes use almost exclusively of natural harmonics. These two features of the work severely constrain the materials available to the composer, but they also offer affordances that are not present on the normally tuned viola. The work, as will be explained below, then becomes in a sense an exploration of the newly designed instrument; the instrument, a filter through which we experience the harmonic series.

2.1.2 Software Environment

The computer-generated sounds in this piece are created in real-time using processes described below that must be triggered either by the performer via a footswitch, or someone in visual contact with the performer. The software, which will be described in detail below, was created in Max/MSP/Jitter¹ and makes use of a number of extensions to that environment written in C by the composer. Figure 2.1 shows the main screen of the Max patch from which the computer operator can control the volume of a number of synthesis processes.

The two most common models (there are many others, to be sure) for compositions

¹<http://www.cycling74.com>

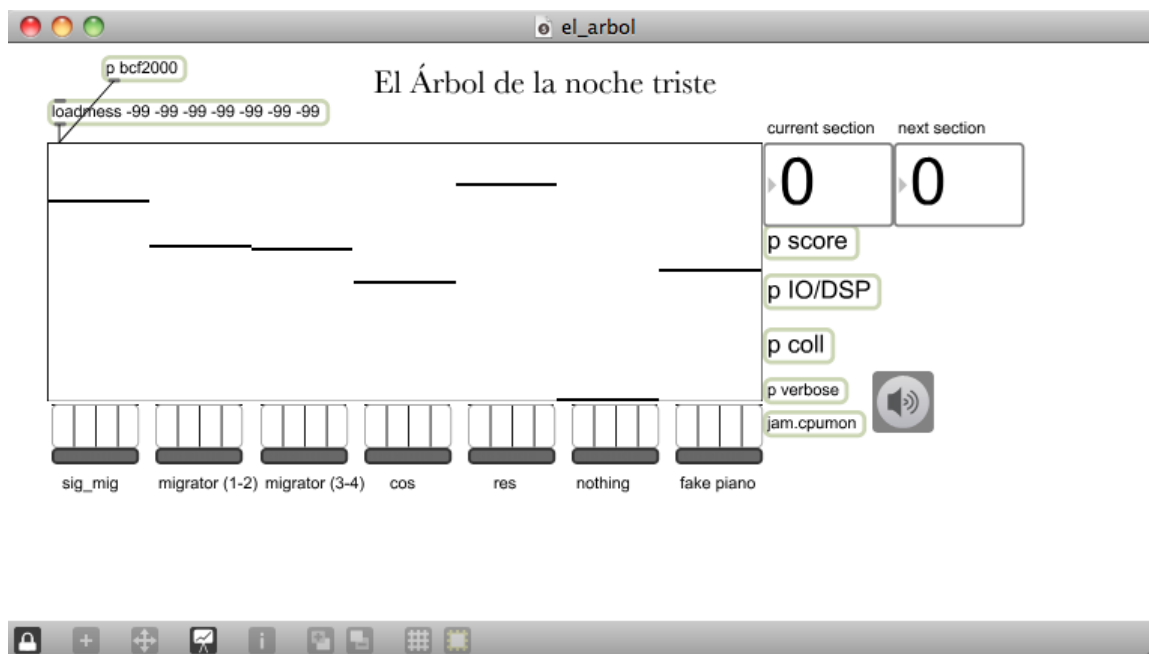


Figure 2.1: The main screen of the Max patch for *El Árbol*.

that include acoustic instruments paired with electronic sounds feature either: 1) real-time electronics created by processing in some way the signal from the acoustic instrument(s), or 2) electronic sounds on a fixed medium such as a sound file to which the performer must synchronize his or her performance. In the former case, the computer is relegated to a set of effects that require the instrument to function, placing the electronic sounds in a role subordinate to that of the instrument. In the latter, the large scale expressive timing of the performer is sacrificed in order to synchronize with the unrelenting temporal rigidity of the material on the sound file.

The goal with this composition was to create a software environment that would bear some behavioral resemblance to the acoustic instrument while allowing the violist to perform unhindered.

2.2 Pitch Material

2.2.1 Viola

The four strings of the viola are tuned to the 5th, 7th, 11th, and 16th partials of a harmonic series

$$f_n = n f_0 \text{ for } n \in \mathbb{Z}^+ \quad (2.1)$$

where f_0 is the fundamental frequency of 27.5 Hz. Table 2.1 shows the deviations in tuning for each of the four strings and figure 2.2 shows graphically how the four strings of the viola relate to the harmonic series. The natural harmonics of each string are all themselves

String	Normal Tuning	New Tuning	Difference (Hz)	Difference (MIDI Cents)	Partial #
A (I)	440.	440.	0.	0.	16
D (II)	293.665	302.5	8.83523	0.513179	11
G (III)	195.998	192.5	-3.49772	-0.311741	7
C (IV)	130.813	137.5	6.68722	0.863137	5

Table 2.1: *Scordatura* applied to the viola.

harmonics of $f_0 = 27.5$ Hz

$$g_n = n f_{st} \text{ for } n \in \mathbb{Z}^+ \quad (2.2)$$

where f_{st} is the partial that the string is tuned to. Table 2.2 lists the natural harmonics of each string in Hertz and figure 2.3 shows them in music notation approximated to the nearest quarter-tone.

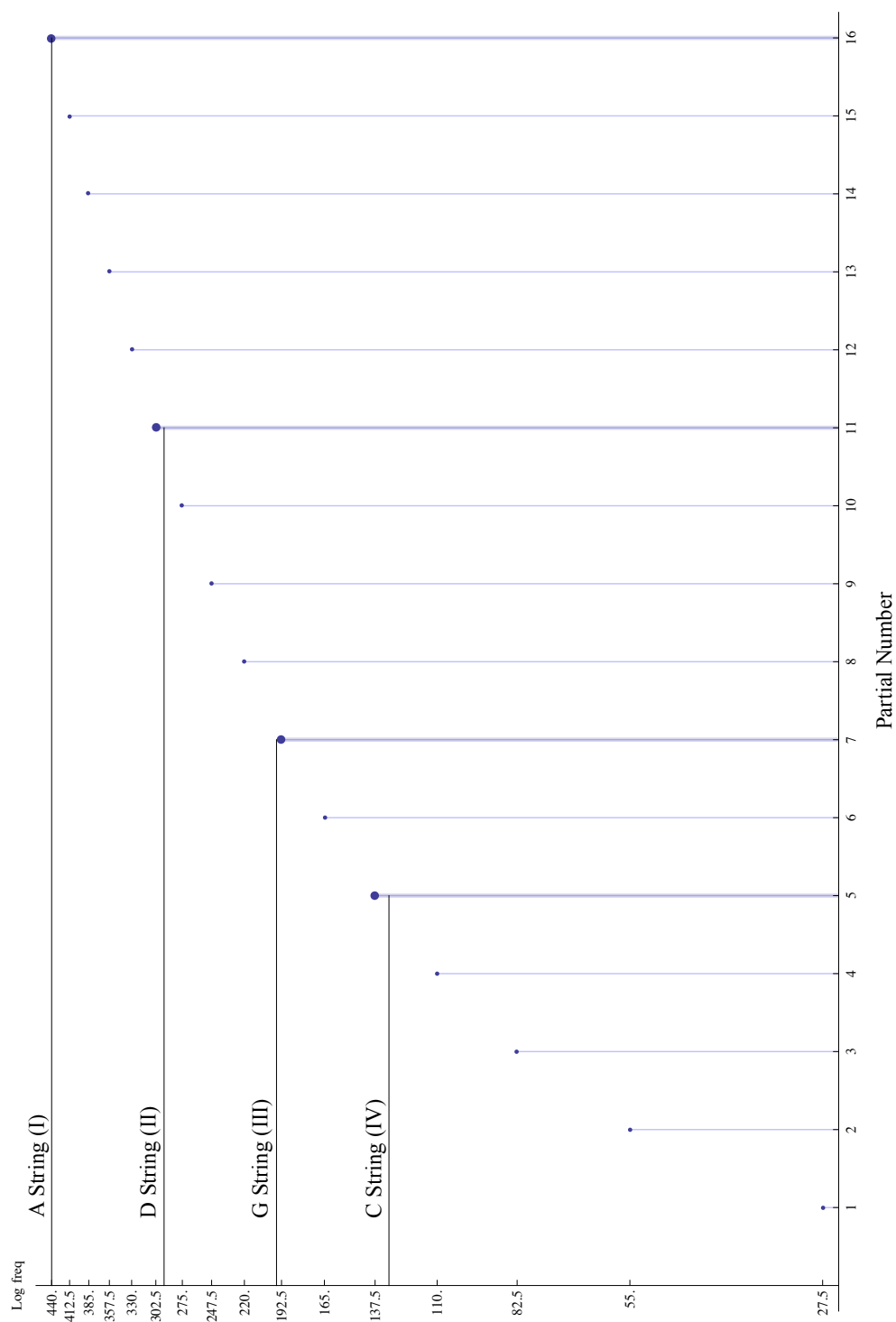


Figure 2.2: The first 16 harmonics above 27.5 Hz with the four strings of the viola. Partial number along the x-axis and log frequency along the y-axis.

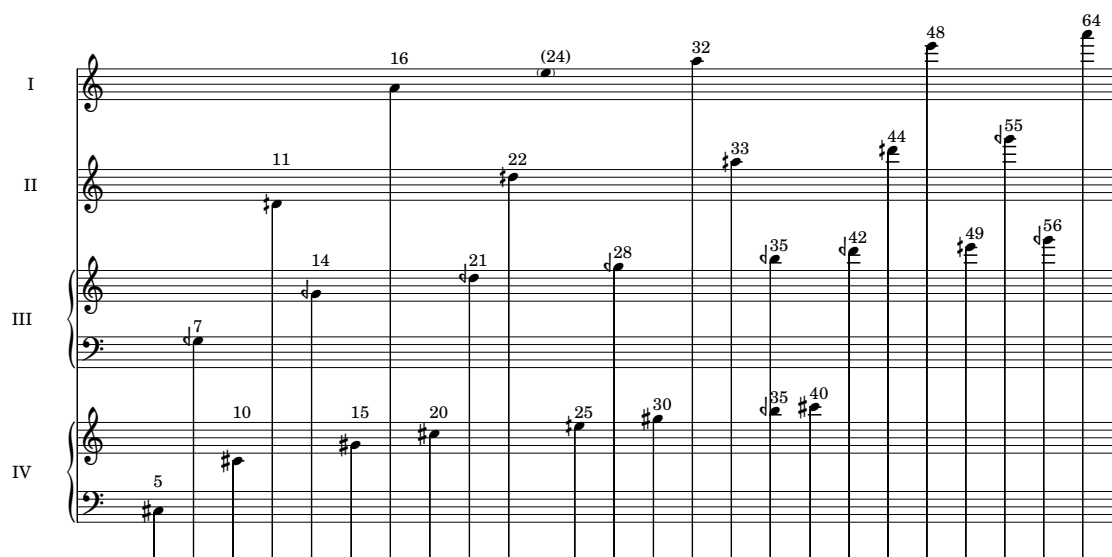


Figure 2.3: Harmonics above the 27.5 Hz fundamental present on the four retuned strings of the viola (approximated to the nearest quarter-tone). The 24th partial is available on the A string as a fingered note.

String	1°	2°	3°	4°	5°	6°	7°	8°
A (I)	440.	880.	1320.	1760.	2200.	2640.	3080.	3520.
D (II)	293.665	587.33	880.994	1174.66	1468.32	1761.99	2055.65	2349.32
G (III)	195.998	391.995	587.993	783.991	979.989	1175.99	1371.98	1567.98
C (IV)	130.813	261.626	392.438	523.251	654.064	784.877	915.689	1046.5

Table 2.2: The harmonics in Hertz on each string of the retuned viola.

2.2.2 Computer

The computer makes use of the so-called hailstone or $3n + 1$ sequence identified by the Collatz conjecture [11] which states that iterating over

$$h_n = \begin{cases} \frac{1}{2}h_{n-1} & \text{for } h_{n-1} \text{ even} \\ 3h_{n-1} + 1 & \text{for } h_{n-1} \text{ odd} \end{cases} \quad (2.3)$$

converges to 1 for all $h_n \in \mathbb{Z}^+$. The $3n + 1$ sequence is a subset of the harmonic series with $f_0 = 1$. Here, we consider the numbers of this sequence to be frequencies in Hertz. Given the divisions by two and the multiplications by three, the resulting sequence is replete with octaves and (slightly mistuned) 13ths. While the addition of 1 Hz may seem insignificant, we should point out that there are fewer than four Hertz between the low C and C \sharp of the cello. The resulting structure, although harmonically complex, has the potential on the local level for a high degree of consonance. The sequence can be seen in figure 2.4 and a detailed view of the first few elements can be seen in figure 2.5.

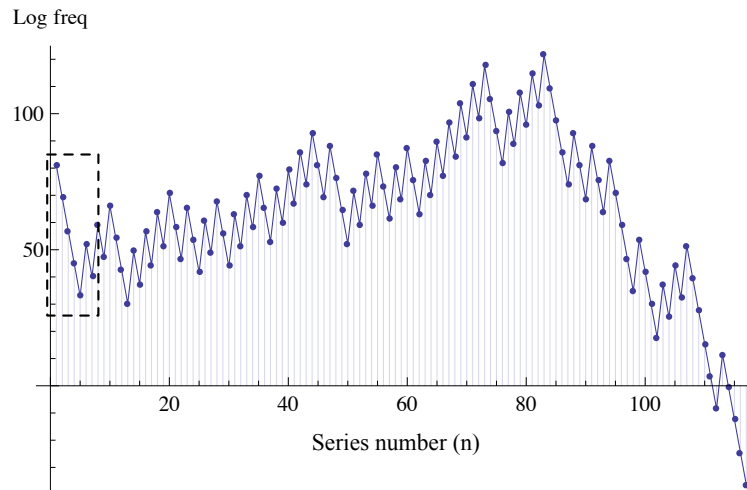


Figure 2.4: Hailstone sequence starting at 880 in log frequency.

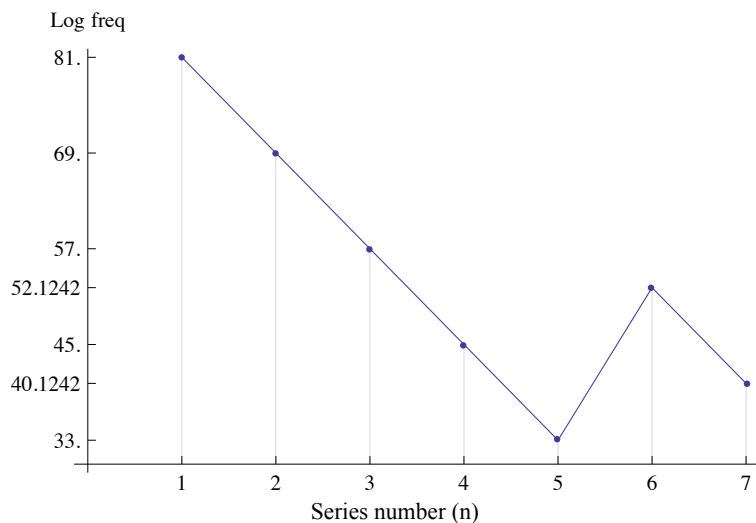


Figure 2.5: Detail of the first seven elements of h_{880} shown in the box in figure 2.4

While h_{880} , considering the elements in Hertz, begins on an A one octave above the A string of the viola and contains some of the harmonics present on the retuned viola, we should point out the (perhaps obvious) fact that the two harmonic series are not built on the fundamental. This is by design; the elements of the harmonic series used in the viola and that of the computer are meant to have some overlap without being overly redundant.

2.3 Intuitive and Algorithmic Composition

All compositional systems can be seen as frameworks that guide the intuitions of the composer. In some cases, such as serialism or the stochastic (ST-*) works of Xenakis, the framework may be quite rigid, however, the intuition of the composer still ultimately governs the characteristic features of the work. One need only look to the second Viennese school to find three composers all employing the same system and yet producing works in at least three very different styles. Serialism, with its far stricter set of rules, still somehow

manages to produce works as different in character, harmonic, and rhythmic profile as Pierre Boulez' *Le Marteau sans maître* and Luigi Nono's *Il Canto sospeso*.

Below, we will discuss elements of the framework present in the viola part of *El Árbol* which is used to guide the musical intuition of the composer. Following that will be a discussion of some of the details of the largely algorithmic computer part.

2.3.1 Viola

Section 1

Recall from the beginning of this chapter that the viola is to be seen as a type of metaphorical filter through which we will experience the abstract harmonic series. The poetic goal of the first section of the piece is to present material that demonstrates the idiosyncratic nature of the instrument by assigning to it musical material that cannot be realized on it. To that end, the musical idea is a simple one: a descending line from the 16th partial, one partial at a time, to the fundamental. The descending line is established in the viola with the 16–14th partials and the missing 13th is filled in by the computer. The 24th stands in for the 12th and then the line is abandoned after the 11th and 10th, the latter up an octave to provide a transition into the next section. The partials available on the viola below the 10th are musically redundant—they have already been presented in the form of their octaves; at this point we have clearly established the original idea and, from a practical standpoint, exhausted our musical material. The descent across the harmonics of the viola can be seen in reduction in figure 2.6 and in the score in figure 2.7.

The durations of each note of the descent were designed to grow shorter expo-

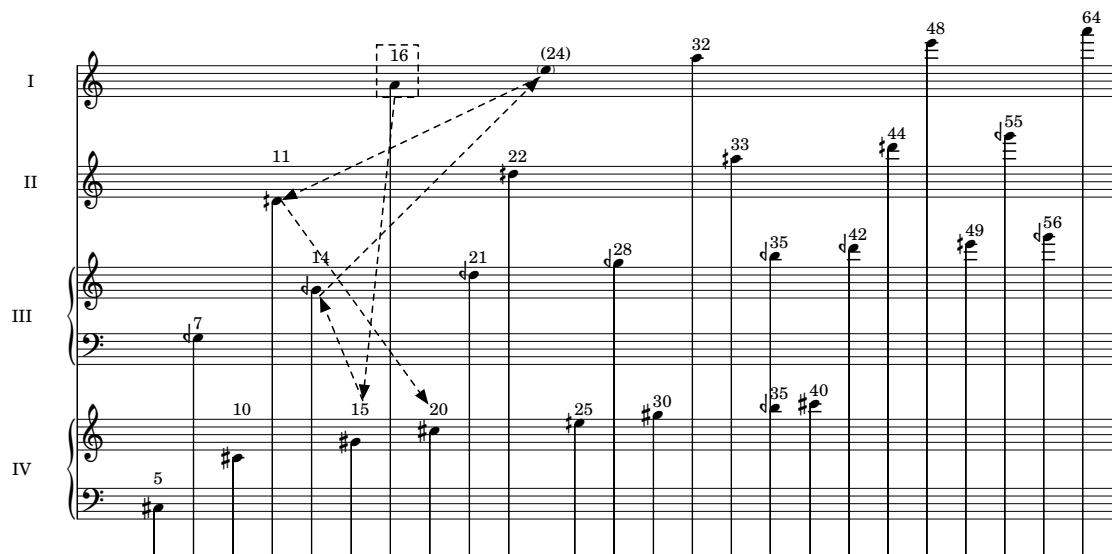


Figure 2.6: The pitch material in the first section of the viola.

nentially over the course of the section. These computed durations were then used as a framework and adjusted as needed for musical reasons. In figure 2.8, we see the pitches placed in time as they appear in the score. In this figure, the 20th, 21st, and 24th partials are all represented an octave lower to emphasize the descending (conceptually, at least) nature of the line. The 13th partial, which exists only in the computer, is shown with a dashed line.

Section 2

The distribution of the harmonics of our low A across the four strings of the viola means that two partials that neighbor each other in the harmonic series may be separated by a large timbral and/or physical gap on the instrument. This is especially the case with the 15th and 16th partials which reside on the fourth and first strings respectively. In the

El Árbol de la noche triste
for Ellen Ruth Rose

John MacCallum

The score is divided into three systems, each with a partial number circled in red:

- System 1 (Partial 16):** Starts with a tempo marking of $J = ca. 55$. The Viola part has a circled 16° . The Computer part has a circled 15° . The Cues part has a circled 15° . Dynamic markings include *ppp*, *mf*, and *mp*. Performance instructions include "one how if possible", "poco sul pont. (don't fade out)", and "(dennse slightly)".
- System 2 (Partial 14):** The Viola part has a circled 14° . The Computer part has a circled 13° . The Cues part has a circled 13° . Dynamic markings include *ppp*, *mf*, and *mp*. Performance instructions include "lip", "v", "vibato", and "S/A".
- System 3 (Partial 10):** The Viola part has a circled 11° . The Computer part has a circled $20^\circ/21^\circ/22^\circ$. The Cues part has a circled $20^\circ/21^\circ/22^\circ$. Dynamic markings include *ppp*, *mf*, and *f*. Performance instructions include "poco f/ant" and "(5*) Slow gradual migration from approx. C3 to approx. A5 without glissandi)".

Figure 2.7: Descending line from the 16th partial to the 10th in the first section.

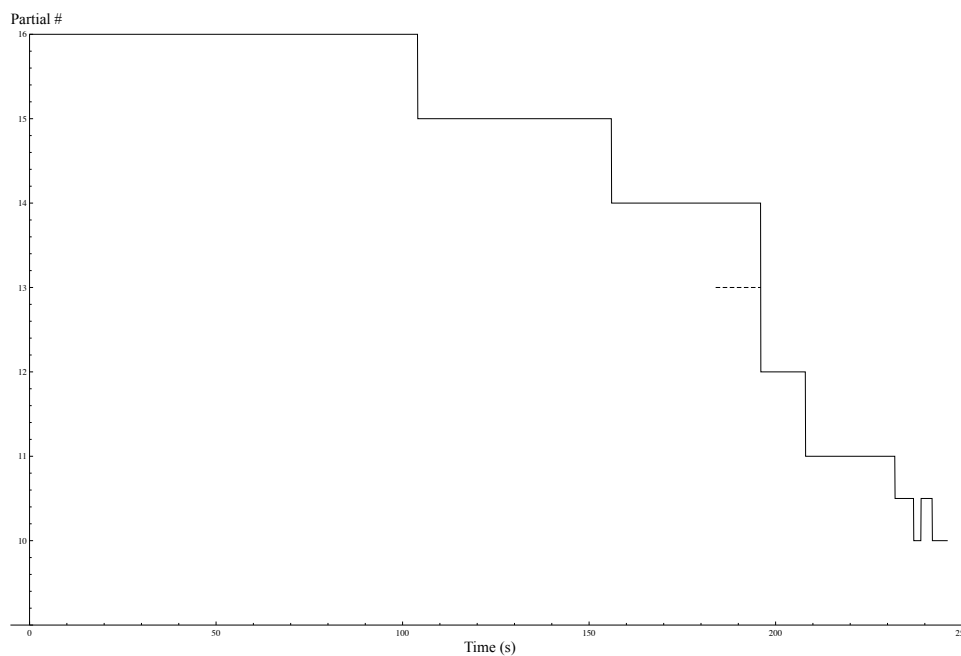


Figure 2.8: The pitches of the descent and their placement in time.

second section of *El Árbol*, we present that aspect of the instrument by alternating the 20th, 21st, and 22nd partials with the open strings on which they reside, partials 5, 7, and 11. The 24th partial, which is the only fully stopped note in the piece, also appears for timbral contrast.

The original intention of the section was for it to be a largely algorithmic presentation of the all or most of the different combinations of the seven elements seen in figures 2.9 and 2.10. However, some combinations proved to be more interesting and technically feasible than others. Rhythmic figures were designed to highlight the disjunct nature of the material and provide contrast to the largely stepwise movement of the first section.

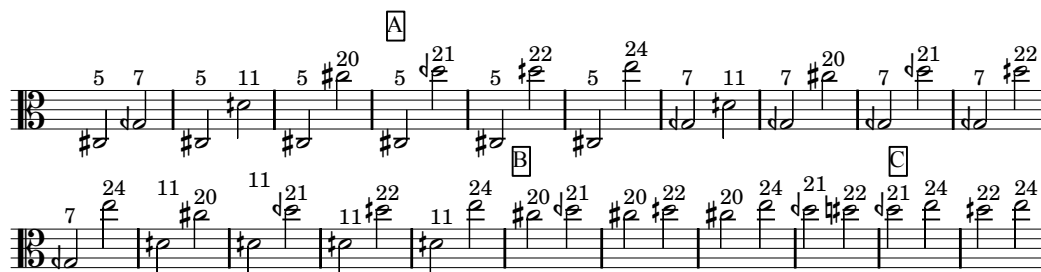


Figure 2.9: $\binom{7}{2}$ combinations of partials 5, 7, 11, 20, 21, 22, 24. The boxed letters correspond to those in figure 2.11

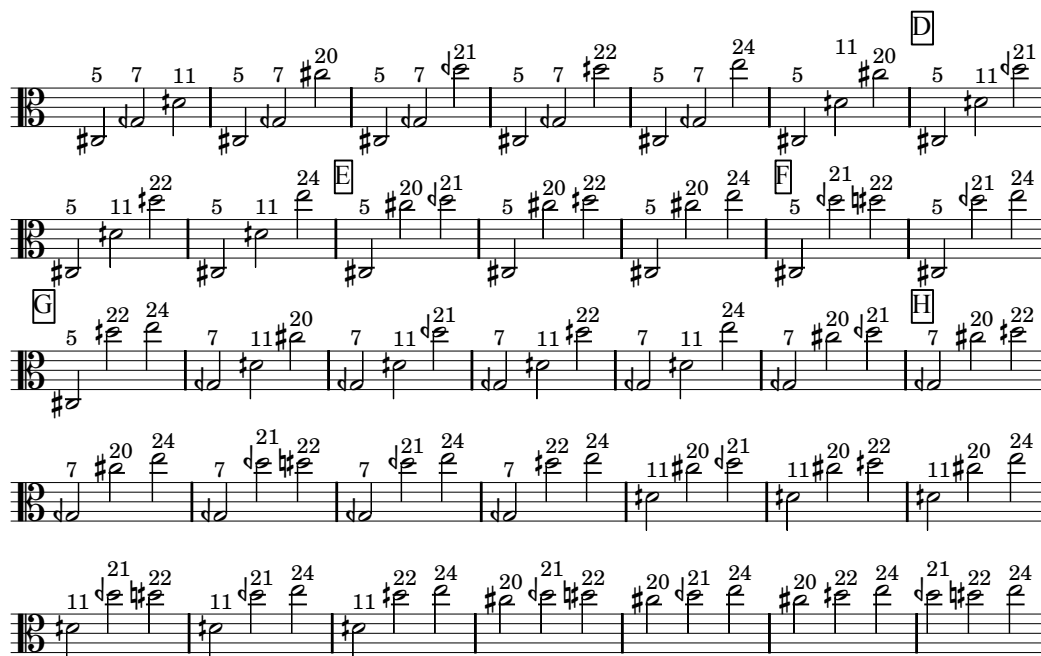


Figure 2.10: $\binom{7}{3}$ combinations of partials 5, 7, 11, 20, 21, 22, 24. The boxed letters correspond to those in figure 2.11

Section 3

The final section is in some ways a return to the beginning of the work and begins with the 32nd partial (an octave above the note with which the piece began) paired with

the 33rd. Following a brief outburst of *quasi* improvised material reminiscent of that from the second section, the piece concludes with the 15th and 14th sounded together, as if to suggest a restatement of the initial descent.

2.3.2 Computer

In the previous section, we discussed the use of the musical material as a way of interrogating the nature of the instrument to which the material was assigned. Here, we use a similar approach, but one that is tailored to the computer.

We select random frequencies from the hailstone sequence h_{880} by first dividing the sequence into eight equally sized bins eight semitones wide. We then use the multinomial distribution

$$P(X_1 = x_1, \dots, X_n = x_n; p_1, \dots, p_n) = \frac{N!}{\prod_{i=1}^n x_i!} \prod_{i=1}^n p_i^{x_i} \quad (2.4)$$

where $\sum_{i=1}^n x_i = N$, $x_i \geq 0$, and $p_i > 0$, to select some number of components from each bin. We can either set the parameters of the multinomial distribution manually, or distribute them using the conjugate prior Dirichlet distribution

$$P = (P_1, \dots, P_n) \sim \text{Dir}(X_1 = x_1, \dots, X_n = x_n; \pi_1, \dots, \pi_n) = \frac{\Gamma\left(\sum_{i=1}^n \pi_i\right)}{\prod_{i=1}^n \Gamma(\pi_i)} \prod_{i=1}^n x_i^{\pi_i - 1} \quad (2.5)$$

where $x_1, \dots, x_n \geq 0$, $\sum_{i=1}^n x_i = 1$, and $\pi_1, \dots, \pi_n > 0$. The parameters of the Dirichlet distribution in turn can either be set manually or randomly distributed uniformly. This allows for a great deal of flexibility; by setting the multinomial parameters manually to the same value $p_i = 1/N$, we can ensure that the resulting subset of h_{880} will be evenly distributed across the log frequency spectrum. We can also easily favor different regions of the spectrum by carefully choosing how the parameters are set, or allow the top parameters

of the Dirichlet distribution to be set randomly yielding a statistically even distribution over a number of choices with a great degree of variation from choice to choice.

Once we know the number of choices that will be made from each bin, we sample from them without replacement, i.e. each frequency in the bin can only be chosen once, using the multivariate hypergeometric distribution

$$P(X_1 = x_1, X_2 = x_2, \dots, X_t = x_t) = \frac{\prod_{i=1}^t \binom{N_i}{x_i}}{\binom{N}{n}} \quad (2.6)$$

where $\sum_{i=1}^t x_i = n$ and $0 \leq x_i \leq N_i$ for $i = 1, \dots, t$. The chosen pitches are then sent, interleaved with equal weights, to a probabilistic synthesizer called the *migrator* developed by David Wessel and the author [7].

The implementation of the system described above was done in Max using the `randdist` object developed by the author. A screenshot of the patch can be seen in figure 2.12, and the results of five trials can be seen in appendix B.

The *migrator* is fully documented in [7]; here we will present a brief overview of how it works. The *migrator* takes as input an interleaved list of frequencies and weights and outputs an interleaved list of frequencies and equal amplitudes suitable for an oscillator bank such as the Max/MSP object `oscillators~` developed by Adrian Freed at CNMAT.² The output list is constantly being updated at an interval of 25 ms. At each update, one oscillator is silenced and a new frequency for that oscillator is chosen from the list of input weights. The method of updating a single oscillator at a time makes very smooth timbral transformations possible and also creates a sense of continual spectral evolution even when the input is not changing.

²<http://cnmat.berkeley.edu/downloads>

For each of the events in the computer part of the score, the above process is enacted with different parameters that were carefully composed as the viola part was being written.

2.4 Deterministic and Indeterministic Composition

The apparent incongruity of the deterministic viola part paired with the stochastic computer part warrants a brief discussion. Within a given compositional framework, there are often many choices that could satisfy the musical requirements at any given moment in the piece. As composers wishing to produce a fully notated score for instrumental performance, we are forced for reasons of practicality to make a decision that privileges one over all others.³ The computer makes no such demands and can be left to generate material within a given framework as a performance of the composition unfolds.

³A discussion of indeterminate scores and notated improvisation is beyond the scope of the current work. We will simply comment that such works require a performance practice that extends beyond the traditional act of interpreting a score introduce issues of performance and composition that were not meant to be addressed in *El Árbol*.

Appendix A

El Árbol de la noche triste Score

The full score to *El Árbol* is listed here. The associated software can be downloaded from <http://www.cnmat.berkeley.edu>.

John MacCallum
El Árbol de la noche triste
for Ellen Ruth Rose

Scordatura:

The strings of the viola are tuned to the 5th, 7th, 11th, and 16th partials of the low A of a piano (27.5 Hz). Relative to the normal tuning of the viola's strings, the C string is tuned almost a semitone sharp, the G is slightly flat, the D is almost exactly a quarter-tone sharp, and the A is normal.

I: 440 Hz
II: 302.5 Hz
III: 192.5 Hz
IV: 137.5 Hz

Notation:

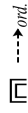


Pitchless noise: Mute the string with the left hand and bow at a roughly 45° angle *sil. tasto* with the tip of the bow.



Natural harmonic: The black note indicated in parentheses is the string on which the harmonic should be played (remember that due to the *scordatura*, this sounding G will not be the same as the 2nd partial of the G string). The top note is the sounding pitch notated without any microtonal indications, i.e., this is the pitch that would sound if the C string were tuned normally.

Positions are not indicated—if a harmonic can be produced in more than one position on the indicated string, you may choose which position to use.



Overbow: This should be a low, rich, growl—not entirely pitchless. If possible, bring the subtone out. Whatever bowing technique is used, give preference to one allows for a smooth transition from this overbowed sound to *ordinario*.

*"Trescientas rosas morenas
 llena tu pechera blanca.
 Tu sangre rezuma y huele
 alrededor de tu fiña.
 Pero yo ya no soy yo
 Ni mi casa es ya mi casa."*

Three hundred dark roses
 cover your white shirt.
 Your blood oozes and reeks
 around your sash.
 But I am no longer I,
 nor is my house any longer my house."

—García Lorca, *Romance sonámbulo*

*Ahora todo está por el suelo, perdido, que no hay cosa.
 Now all is in the dust, lost, there is nothing left.
 —Bernal Díaz del Castillo*

Appendix B

Five Randomly Chosen Sets of Pitches

On each of the following five pages, we find data collected from the system described in section 2.3.2. On each page, the data is presented four different ways, two in music notation and two as Cartesian plots. Where the data is displayed as music notation, the frequencies are rounded to the nearest quarter-tone and displayed as a chord and a linear series. In the first of the two plots, the natural order of the hailstone sequence is retained, while the second places log frequency along the x-axis. In both plots, vertical lines indicate which elements were randomly selected, and the two dashed lines delineate the range from which the frequencies were chosen (137–5000 Hz).

Although the data was collected for the purposes of this document, the five pitch collections below could correspond to the first, fifth, seventh, ninth, and eleventh cues notated in the electronic part of the score.

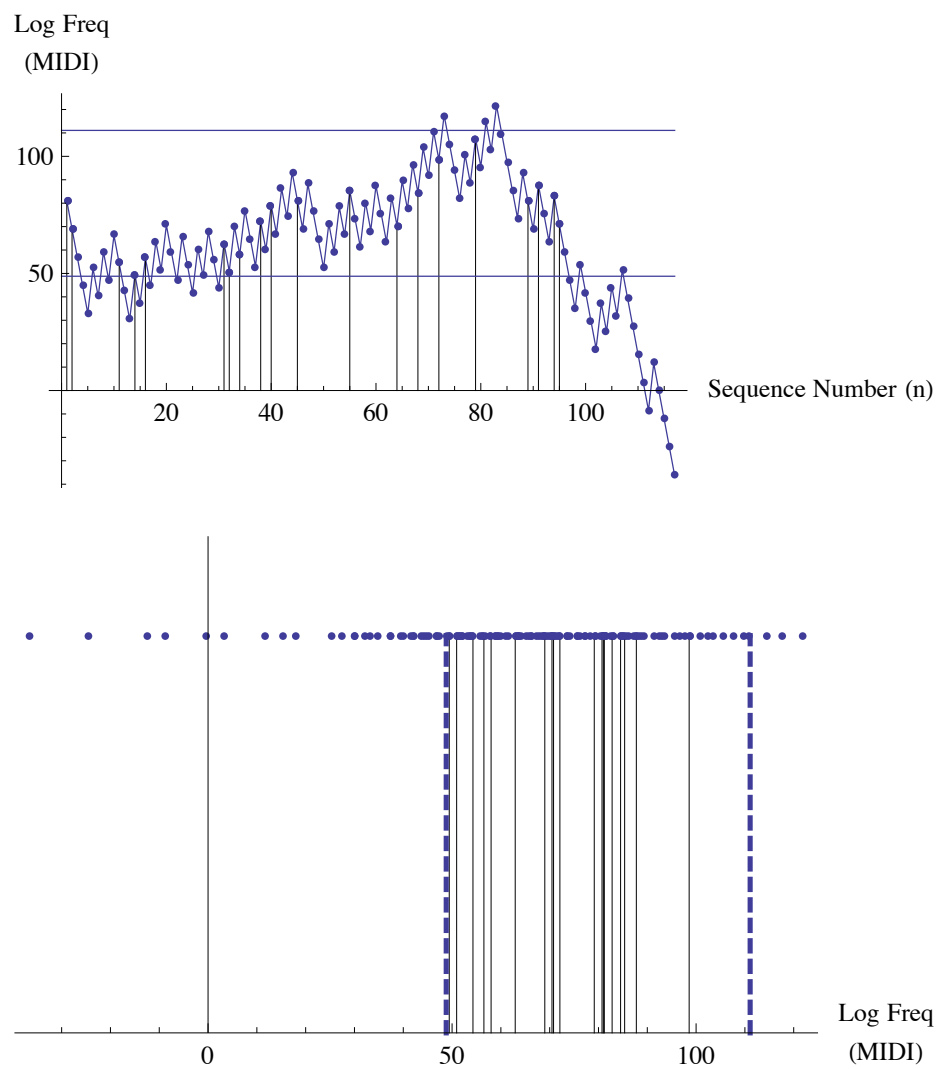


Figure B.1: Random pitches chosen in the computer part at the first cue.

Musical score for piano and violin/viola. The piano part is in the lower register, and the violin/viola part is in the upper register. The score includes dynamic markings *8va* and *15ma*.

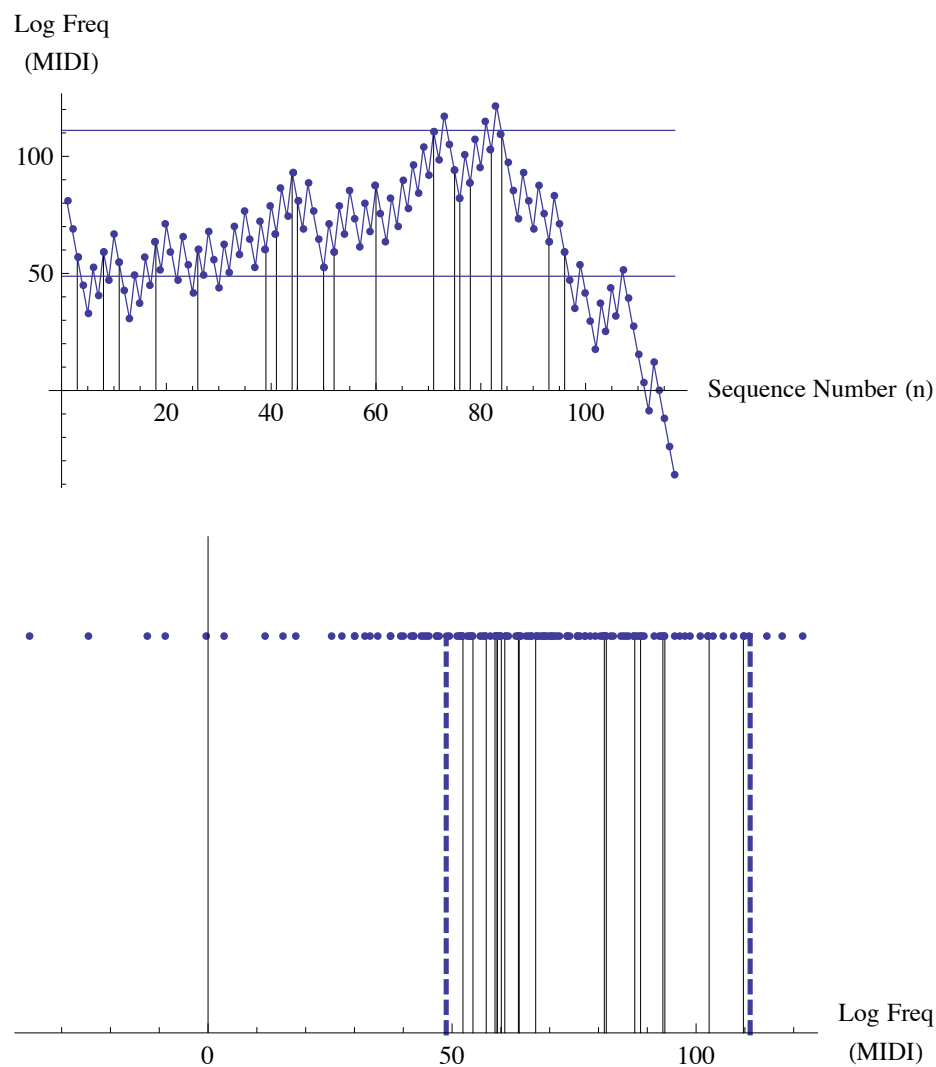


Figure B.2: Random pitches chosen in the computer part at the fifth cue.

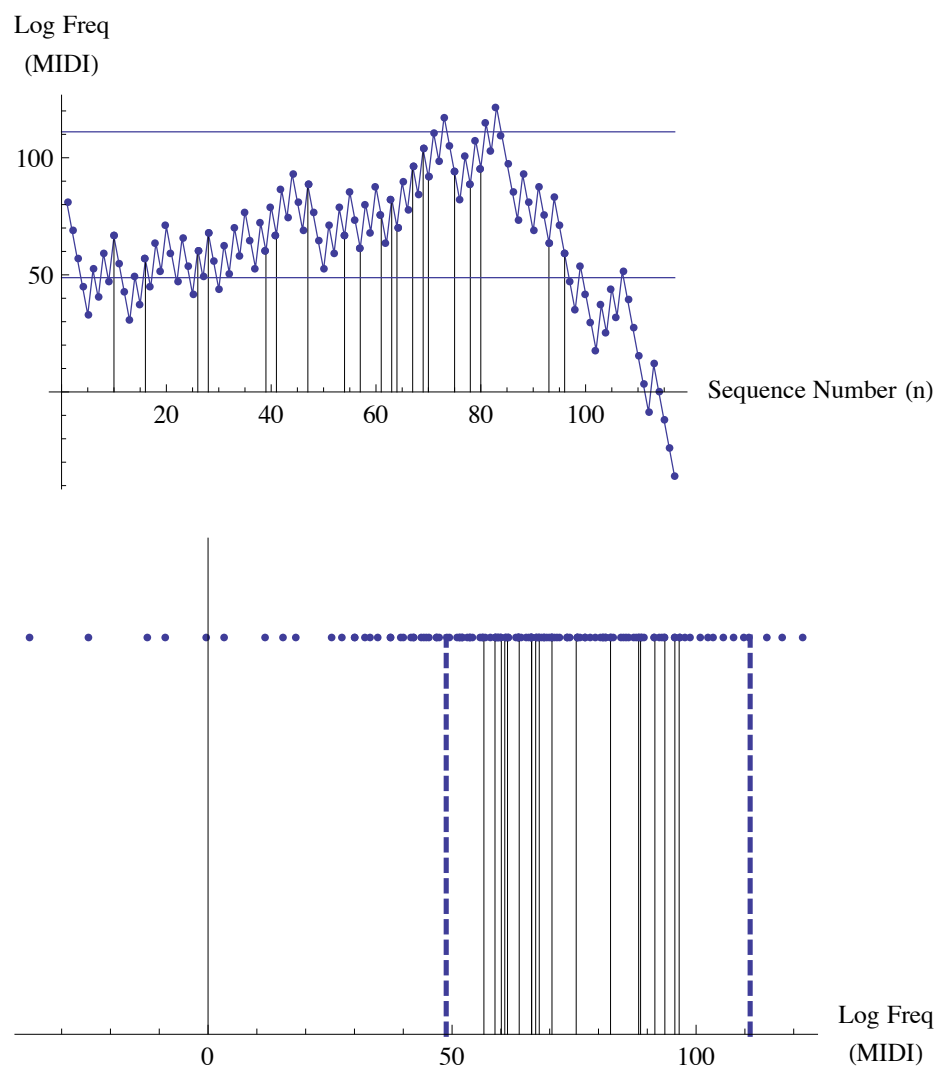
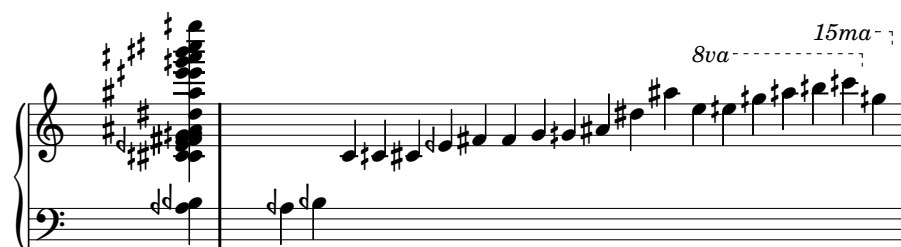


Figure B.3: Random pitches chosen in the computer part at the seventh cue.

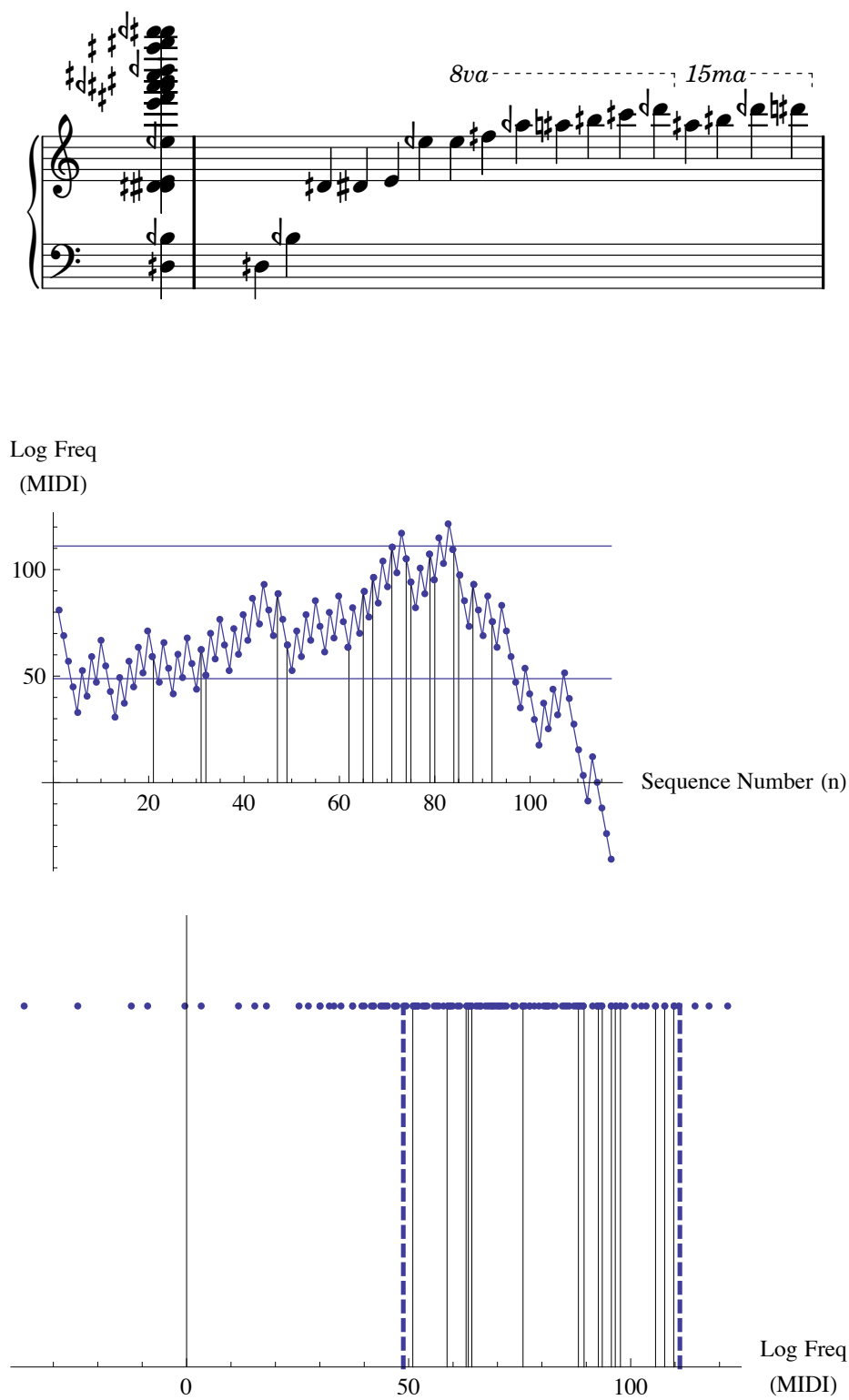


Figure B.4: Random pitches chosen in the computer part at the ninth cue.

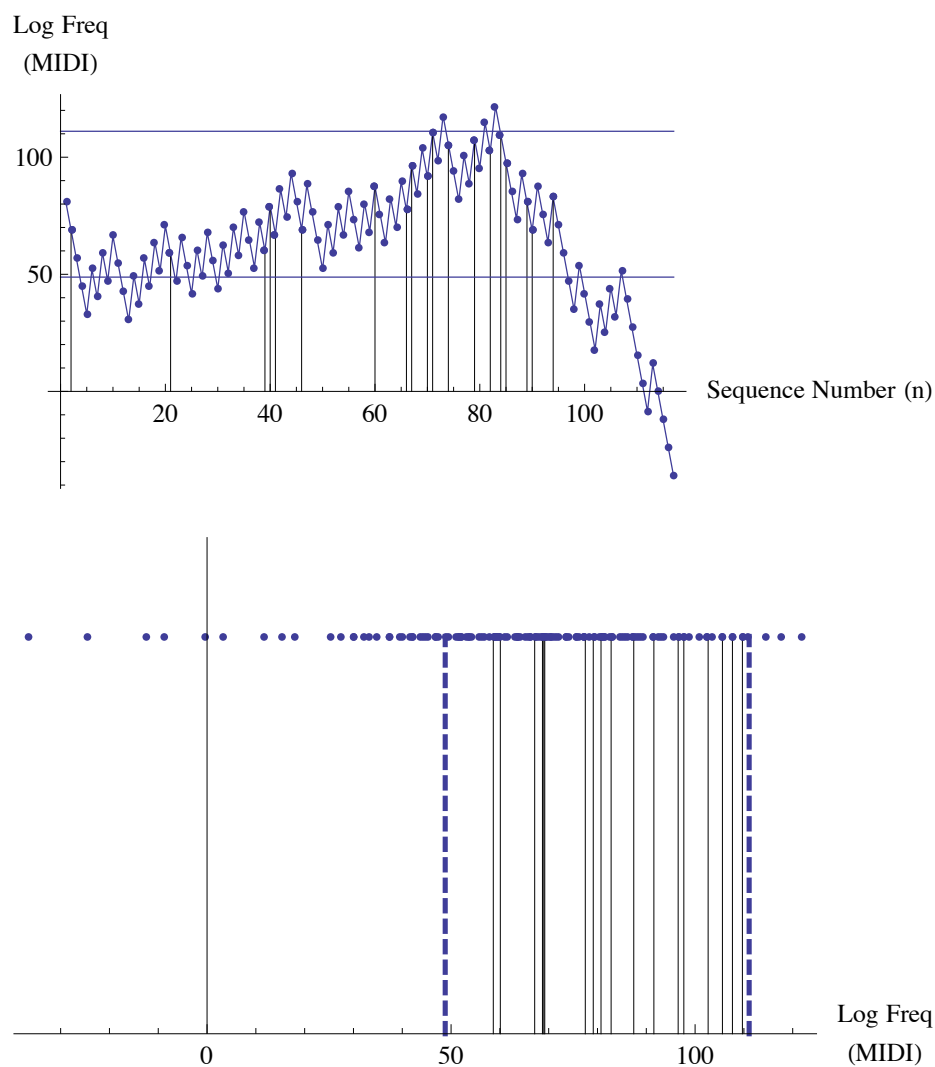
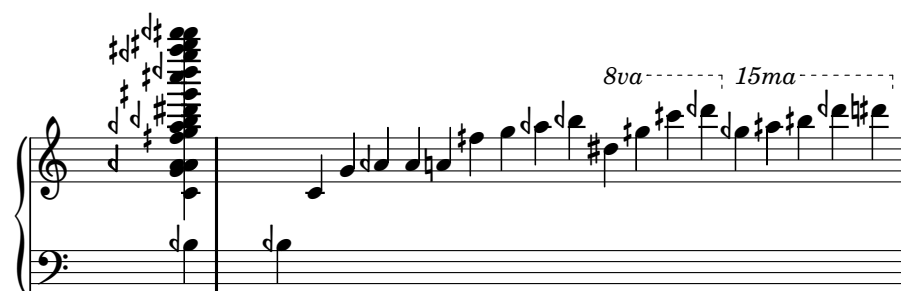


Figure B.5: Random pitches chosen in the computer part at the eleventh cue.

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