UNIVERSITY OF CALIFORNIA, SAN DIEGO

Ouroboros and *Apocryphal Chrysopoeia*: Aesthetics and Techniques

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

in

Music

by

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The Dissertation of Paul James Hembree is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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ABSTRACT OF THE DISSERTATION

Ouroboros and *Apocryphal Chrysopoeia*: Aesthetics and Techniques

by

Paul James Hembree

Doctor of Philosophy in Music

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Professor Roger Reynolds, Chair

Resources from a variety of disciplines were gathered, compared and woven together to create *Ouroboros*, an eighteen-minute work for large chamber ensemble and audio-visual media, as well as the programming of *Apocryphal Chrysopoeia*, a software instrument used to create the audio-visual components of *Ouroboros*. The temporal structure and thematic subject matter of this work are based on a text collage that dwells upon the peril and promise of automata. This collage is a palimpsest of Heinrich von Kleist's “On the Marionette Theatre,” overlaid upon E.T.A. Hoffmann's *The Sandman*, both in English translation. Furthermore, excerpts of non-fiction critical texts dealing

with the use of abstraction and algorithms in the creation of music serve as textual interludes during the narrative structure of the Hoffmann-Kleist palimpsest. The resulting text is projected as supertitles during the performance. The ensemble music and audio-visual media were composed to respond to the text, sometimes empathizing with it, and other times moving indifferently to it.

Algorithmic processes, abstractions based in music psychology, and structures related to the physics of real and imagined instruments guide the music and audio-visual media in *Ouroboros*. The changing spatial relationships of audio-visual modules in the virtual instrument *Apocryphal Chrysopoeia* produce the modulation of harmonic fields, bounding the pitch material for both the electronic and acoustic instruments. A pitch space model extrapolated from work by Roger Shepard determined the basic spatial arrangement of these modules. However, it was discovered that distortion of this spatial model was required to continually refresh the harmonic material.

A cellular automaton articulates this pitch space model in time, creating variegated but principled patterns in both sound and light. This sound-light activity is mediated by a variety of effects aimed at finding points of synchresis between auditory and visual behaviors, drawing upon the visual music tradition for inspiration. Alongside this audio-visual behavior, the music composed for acoustic instruments frequently involves imitative counterpoint in multiple tempi, a process bound by the harmonic fields found in the audio-visual instrument. Furthermore, specific instrumental techniques, most notably split-tone multiphonics on the trumpet, were explored to find timbral connections between the acoustic and electronic domains.

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Ouroboros and *Apocryphal Chrysopoeia*: Aesthetic and Techniques

1.1 Introduction

Much of my work over the last six to nine years, including my dissertation composition, *Ouroboros*, has involved testing the limits of the usefulness of abstract processes and their mapping onto musical behaviors, whether automated in some way with the computer, or worked out by hand. Many of these processes have essentially been found objects[1]; models and simulations of natural phenomena, chosen for their parallels with musical behaviors. I am particularly attracted to phenomena that can be modeled through iterated processes that incorporate feedback. Frequently the fusion of these borrowed concepts with music was aided with other abstractions found in music perception studies – typically any kind of spatial or numeric representation of the perceived relationships in music.

My attraction to these models of natural phenomena comes from my aesthetic gravitation towards the experience of the sublime, of which the classic definition by Edmund Burke (1729 – 1797) is useful: “an ecstasy of terror that fill[s] the mind completely.”[2] The traditional locus of the sublime is nature, but I am also attracted to the aesthetic qualities of nature simulated with the computer, and with sufficient audience immersion, I believe that these technologically aided simulations can approach the sublime experience. Furthermore, I have been interested in the experience of the uncanny as well, particularly the possibility of eliciting it through life-like automata. However, my outlook on the uncanny in experiences aided by audio-visual production

1 Makis Solomos productively compares Iannis Xenakis' manual interventions with his formalized procedures to *bricolage,* assembling together found objects, in "Cellular automata in Xenakis's music: Theory and Practice," in *Definitive Proceedings of the International Symposium Iannis Xenakis* (Athens, May 2005-2006), 3.

2 David E. Nye, *American Technological Sublime* (Cambridge, MA: MIT Press, 1995), 6.

technology has sobered somewhat, with the realization that dazzling simulations have come to be expected in media arts with high production values. I now believe that the uncanny experience must be truly unexpected, and is therefore unlikely to be part of pre-planned technological spectacle.[3]

Furthermore, I have become aware of the limitations of working with abstractions or models of natural phenomena, particularly ill-conceived direct mappings between non-musical and musical data. This awareness of the limitations of abstraction, wariness over potential pitfalls into scientism, and a mild paranoia about whether technological progress is progress at all, has lead me to search for both literary and critical texts dealing with these subjects. I assembled a collage of these texts to serve as a narrative scaffolding for creative explorations with the very technological tools the texts criticized. It is this self-reflexivity that gave the dissertation composition its title: *Ouroboros*, the “tail-devourer,” a sigil representing the cyclical nature of creation and destruction.[4]

1.1 Landscape Paintings of the Information Age

My first explorations of the sublime as part of aesthetic experience involved studying the music of Conlon Nancarrow (1912 – 1997), who has been a constant source of inspiration for me over the last fifteen years. Scholar Eric Drott notes that Nancarrow's player piano music is typically described with a plethora of violent nature metaphors, including “'blizzards,' 'avalanches,' and 'showers' ” of notes, a “tempestuous embodiment of some primeval natural force, which undertakes a physical assault on the

3 The uncanny is perhaps more native to stage magic, and it would seem wise to distance one's art from stage magic.

4 Carlos Erie, *A Very Brief History of Eternity* (New Jersey: Princeton University Press, 2011), 29.

listener's faculties."[5] Drott explicitly drew from historian David Nye's *American Technological Sublime* (1994) in attempting to describe Nancarrow's aesthetic tendencies with the use of his two Ampico player pianos. Nye himself bases his discussion upon definitions of the sublime from Edmund Burke (1729 – 1797) and Immanuel Kant (1724 – 1804). According to Burke, as mentioned before, the sublime experience grew "out of an ecstasy of terror that filled the mind completely. The encounter with a sublime object was a healthy shock, a temporary dislocation of sensibilities that forced the observer into mental action."[6] Nye structures his book based on Kant's theories in the *Critique of Judgement* (1790),[7] dividing the sublime experience into two forms: "the mathematical sublime (the encounter with extreme magnitude or vastness, such as the view from a mountain) and the dynamic sublime (the contemplation of scenes that arouse terror, such as a volcanic eruption or a tempest at sea, seen by a subject who is safe from immediate danger)."[8] Nye goes further to argue that in the twentieth century and beyond, technology has become capable of producing either form of the sublime in human experience, along side, and often superseding nature.

The mathematical and dynamic aspects of the sublime, encountered frequently via natural phenomena, have served to stimulate my compositional activities over my graduate career. I'm also interested in the way that science has opened windows into the inner-workings of these phenomena, and the art works that these new windows have influenced, either through evocation of the phenomena, or through direct use of models and information about those phenomena. I would prefer to have evocation in addition to

5 Eric Austin Drott, "Nancarrow and the Technological Sublime," *American Music* 22 (Winter 2004), 533-563.
6 Nye, *American Technological Sublime*, 6.
7 Immanuel Kant, *Critique of Judgement* (1790), reprint, trans. J. H. Bernard (London: Macmillan, 1914).
8 Nye, *American Technological Sublime*, 6.

utilization of models, but sometimes direct mapping of models onto the perceivable dimensions of an artwork does not yield results that evoke the original phenomena – although the results may be new and interesting in their own right.

Examples of the influence of science on the visual arts include Gerhard Richter's (b. 1932) oppressive mural, *Strontium* (2005), composed of digitally manipulated photos of strontium titanate molecules in their crystalline form[9], or the work of Frederik de Wilde (b. 1975), particularly his data-based sculptures and computer generated images, as well as his ultra-black, carbon nanotube-based paint, which was itself designed in collaboration with several scientists.[10] In music, I've been attracted to György Ligeti's (1923 – 2006) evocations of fractals, such as the fourth movement of his *Piano Concerto* (1989),[11] and Iannis Xenakis' (1922 – 2001) more direct mappings of formal processes onto music, including his works with arborescences, such as *Lichens* (1983), *Jonchaies* (1977) and *Horos* (1986).[12] In the audio-visual realm, I find that the visual-music duo NoiseFold[13] (David Stout and Cory Metcalf) and the Interactive Swarm Space[14] team, lead by Daniel Bisig, have created the most compelling and occasionally sublime interactive multimedia works utilizing models of natural phenomena.

The evocation of sublime nature is normally associated with romantic, nineteenth century landscape paintings, but media theorist Armin Medosch (b. 1962) identifies a

9 "Gerhard Richter: Strontium, 2005." Fine Arts Museums of San Fransisco: Site-specific art commissioned for the de Young. http://deyoung.famsf.org/about/site-specific-art-commissioned-de-young/gerhard-richter-strontium-2005 (May 18, 2015).
10 "From blackest black to universe hacking. An interview with Frederik de Wilde." We Make Money Not Art. http://we-make-money-not-art.com/archives/2014/02/frederik-de-wilde.php (May 18, 2015).
11 Richard Steinitz, "The Dynamics of Disorder," *The Musical Times* 137, no. 1839 (1996), 8.
12 Iannis Xenakis, *Formalized music: thought and mathematics in composition* (Stuyvesant, NY : Pendragon press, 1992), xii.
13 "NoiseFold." http://noisefold.com/ (May 18, 2015)
14 "Interactive Swarm Space." http://swarms.cc/ (May 18, 2015)

thread of romanticism running from this tradition through twenty-first century media arts, particularly those that deal with models of nature or large data sets derived from natural sciences. It is worth summarizing much of his article:

> Romanticism emerged from the contradiction of trying to be one with nature and feeling to be fundamentally separated from it. ... When the romantic youth contemplated nature, they could see, in the shape of the mountain ridges, in this frozen moment of time, the powerful forces at work that were reshaping the world. … Romanticism has never really left the arts, even if it, as an official movement, petered out somewhere at the end of the 19th century. … In media and net art survives *a romanticism noir*… Media and net art increasingly turn to aestheticization of information flows via sonification and visualization. ... The scientific instruments of our time have opened rich pipelines into *the data sources of nature*. With the constructivist[15] instruments of mathematics and engineering the datanauts are diving into oceans of information that represent the physical materiality of the world. ... Now, nature is becoming quantized and quantified, it is being dematerialized and turned into information. ... As artists are getting hold of the techniques of information processing, *landscape painting of the information age* emerges as a major theme in the early 21st century. It shows us nature distilled into information 'flows.' ... [M]edia artists can move into action by building working technological assemblages. ... A working technological assemblage might well have a picture as an end-result, but what makes it really interesting are the inputs and outputs and the processes that happen in between. ... There is modeled a complete world-view, an image of the world and its workings. This image, which is of course not a realistic 'picture' but a constellation of forces, of energies and motives, is constructed as a montage of information flows [my emphases].[16]

I should note that Medosch primarily deals with artists that use large data sets derived from natural or social sources, distilling those sets down to find the principles behind their organization, and exploiting those principles in the process of art-making. Other artists work in the opposite direction, starting with basic principles that can be spun

15 This term is used differently by scholars depending on their specific discipline. It appears that Medosch is pointing out that artists can get a hold of technocratic tools and use them in their own ways.

16 Armin Medosch, “Landscape Painting of the Information Age or Romanticism In Media Art.” *Kritikos* 2 (July 2005), http://intertheory.org/medosch.htm (May 22, 2015).

out to create seemingly natural patterns. Both groups put their trust in abstraction; the former use mathematical tools of regression or multidimensional scaling to make sense of large data sets, while the latter create complex patterns from simple algorithmic rules.

Examples of Medosch's *landscape painting of the information age* do not look anything like traditional landscape paintings. De Wilde, who explicitly thinks of himself as such a "painter," uses "environmental recordings, electromagnetic field and video registrations" to generate "graphical" and "painterly visual abstractions" in his Numerical Recipe Series (NRS).[17]

Figure 1. Frederik De Wilde, *NRS # The World As Seen Through My Eyes In Which I Set Myself On Fire* (2011).

17 Frederik De Wilde, "I Paint With Data _ i.p.w.d = artistic statement : an attempt to redefine traditional painting through media art and generative art." http://frederik-de-wilde.com/wp-content/uploads/2011/07/Website-NRS23.pdf (May 20, 2015).

1.1.1 Atemporal Panoramas Unravelled in Time

Although I find myself strongly tending toward creations involving the technological sublime, my first encounters with the sublime were decidedly not landscape paintings of the information age, or even traditional landscape paintings, but *actual* landscapes. A substantial portion of my youth was spent either recreating or working in the outdoors. Furthermore, my early experience of nature was tempered by exposure to the natural sciences, particularly geology, my father's occupation, which I also studied briefly during my undergraduate studies.

Much to the chagrin of my father, I was always more interested in geomorphology, which is essentially the study of the processes that created the current topography, thus confining much of the age of study to the Holocene epoch (the last eleven-thousand years). I think this is the geological equivalent of hedonism – a focus on a temporarily pleasurable present.

Geomorphology, and geology in general, involves imagining – or forming a hypothesis about – the dynamic processes that created seemingly static structures; temporal processes are inscribed in some way upon apparently atemporal panoramas. Typically there are multiple dynamic processes occurring at different time scales that interact, such as relatively quick processes like erosion interacting with the products of much slower processes like faulting and plate tectonics. Furthermore, all of these processes interact with themselves through feedback: any static configuration in the present effects the flow of the process, and hence the creation of new static configurations.

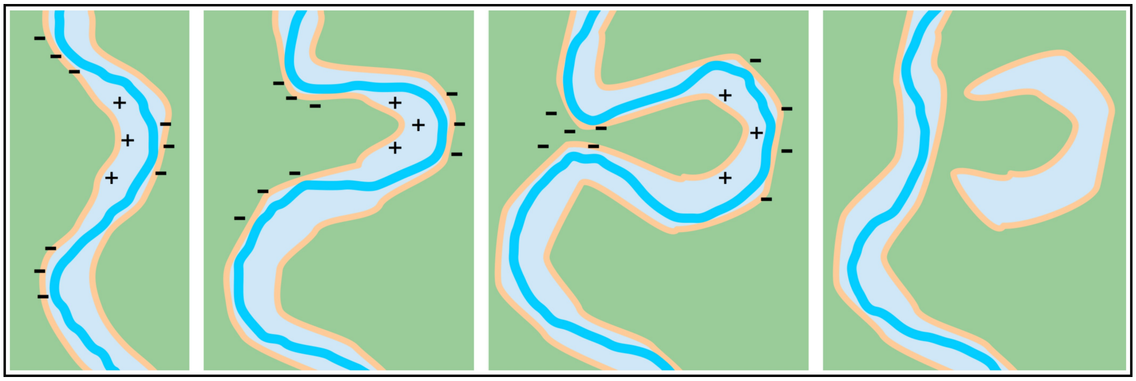

Figure 2. Four successive stages in the evolution of river meanders towards an oxbow lake.

Meandering river beds are an excellent example of this kind of process. As a river cuts through terrain of relatively uniform and malleable composition, it erodes its banks quicker (figure 2, minus signs) where it moves fastest (figure 2, dark blue line), typically at the outside edges of curves. It also deposits whatever sediment it is carrying where it moves slowest (figure 2, plus signs), typically the inside edges of curves. The resulting feedback process of erosion and deposition of sediment creates meanders, and eventually a meander may amplify itself until the isthmus separating two outside edges is cut through, isolating what was once a meander now as an oxbow lake (see figure 2).[18]

Similar iterative processes leading to catastrophic changes in a system have interested me in the composition of linear elements in my acoustic music. Though not explicitly intended as a mapping of meander formation onto melodic composition, the saxophone part (or any one of the wind parts) from measures 158 to 161 of *Ouroboros* (figure 3) displays a similar iterative process that illustrates my aesthetic sensibilities.

In the saxophone line, after an initial C6, the saxophone leaps several times from the inside of the treble staff to the high register. These leaps are followed by stepwise

18 Pierre Julien, *River mechanics* (Cambridge: Cambridge University Press, 2002), 186-187.

descending patterns of increasing length, using the familiar recurrence relation, the Fibonacci sequence (figure 4, numbers above staff). I simply use these numbers to create easily calculated quasi-exponential growth in various musical dimensions.

Figure 3. Braided, canonic melodic lines in *Ouroboros*, m. 158-161.

When eight steps are reached, the ambitus of the stepwise descent catastrophically breaks the mold and descends below the starting pitch for that melodic unit. The contrapuntal line is then picked up elsewhere by another instrument. This melodic line was not the result of a formalized procedure, but was informed by incremental processes building to explosive changes. It should be noted that the pitches available at this moment in the music were predetermined by a harmonic plan (which aligned the activity of the cellular automaton instrument, described later, with the acoustic instruments), and the exact contours and pitch choices were composed with an awareness of the other contrapuntal voices in this texture.

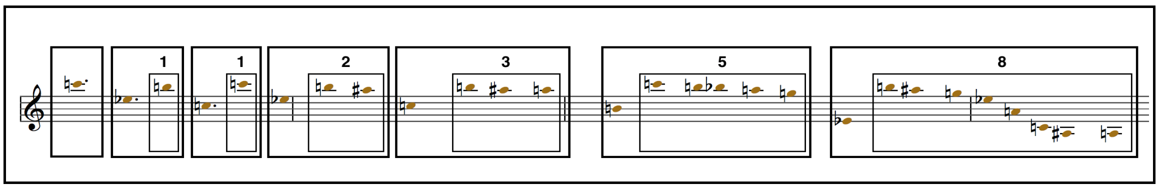

Figure 4. Analysis of the saxophone line in *Ouroboros*, m. 158-161.

Many of the techniques I use in my acoustic music involve simultaneous instances of the same melodic material traveling at different tempi, which are themselves changing at different rates. Musically my influences for this technique primarily come from several sources. Reaching back to the musical Renaissance in Western Europe (roughly from 1400 to 1600),[19] I'm attracted to technique of prolation canon, which involves the use of multiple mensural signs (something roughly like our modern time signatures) to decode the same note values in different ways, effectively creating multiple tempi when performed. Excellent examples include Josquin des Prez's (ca. 1450 – 1521) *Missa L'homme armé super voces musicales* (1502)[20] and Johannes Ockeghem's (1410 – 1497) *Missa prolationum* (ca. 1475).[21] More recently, some of the music of Conlon Nancarrow

19 Allan W. Atlas, *Renaissance music: music in Western Europe*, 1400-1600 (New York: Norton, 1998).
20 Patrick Macey, et al, "Josquin des Prez," in *Grove Music Online. Oxford Music Online*. Oxford University Press. http://www.oxfordmusiconline.com/subscriber/article/grove/music/14497-2001-01-20pg12 (May 19, 2015).
21 Leeman L. Perkins, "Ockeghem, Jean de," in *Grove Music Online. Oxford Music Online.* Oxford

features canons with voices in multiple tempi, which are themselves accelerating and decelerating at different rates. His player piano *Studies Nos. 8, 21, 22, 23* and *27* (1948-1960), and the end of *String Quartet No. 3* (1987) all use this technique.[22]

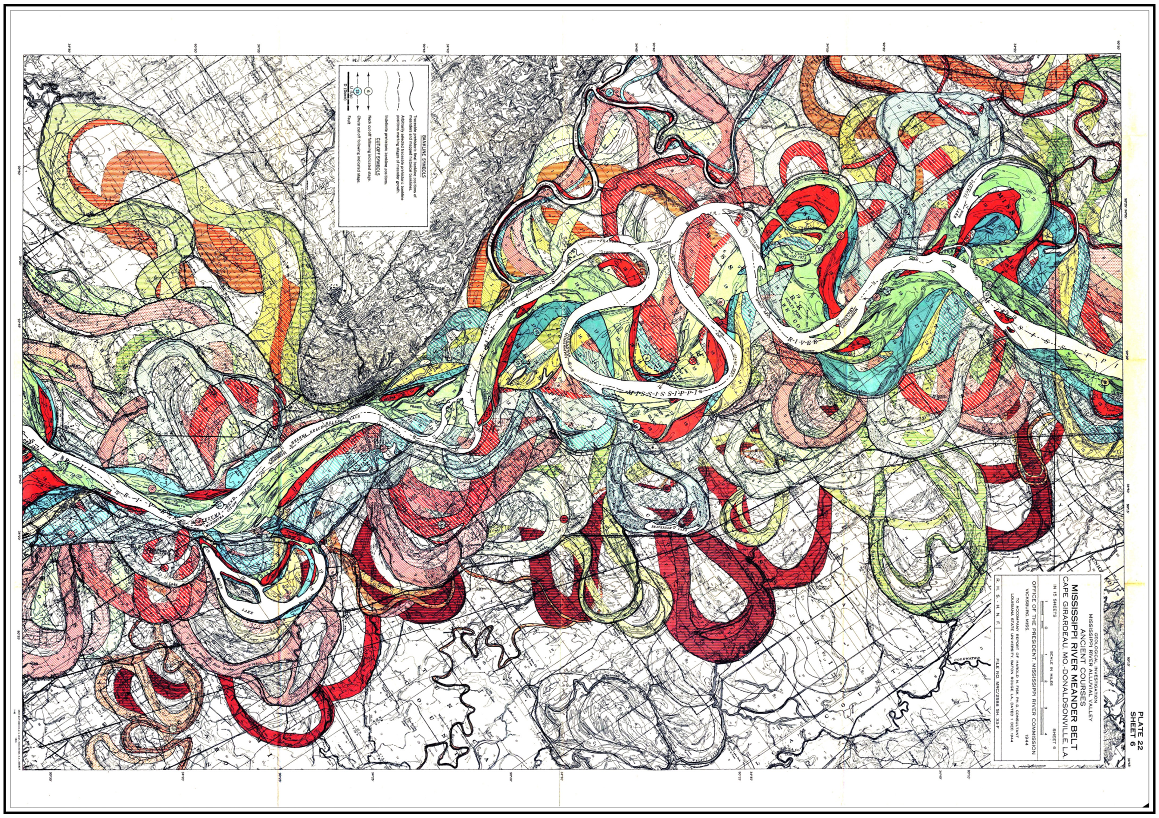

Figure 5. Geologic map of Mississippi River meander belt, near Helena, AR.[23] Note the meander in the center of the map that has nearly begun to be cut off from the main course of the river.

György Ligeti's piano etude *Automne à Varsovie* (1985) features canons in multiple tempi, realized through a common super-fast pulse,[24] and Gérard Grisey (1946 – 1998) depicts the deluge in the Epic of Gilgamesh in the final movement of *Quatre*

University Press. http://www.oxfordmusiconline.com/subscriber/article/grove/music/20248 (May 19, 2015).

22 Kyle Gann, *The music of Conlon Nancarrow* (Cambridge: Cambridge University Press, 1995), 10.

23 Harold Norman Fisk, "Geological investigation of the alluvial valley of the lower Mississippi River," Lower Mississippi Valley Engineering Geology Mapping Program (Vicksburg, MS: War Department, Corps of Engineers, 1944). http://lmvmapping.erdc.usace.army.mil/index.htm.

24 Mayron K Tsong, "Études pour piano, premier livre of Gyorgy Ligeti studies in composition and pianism" (Ann Arbor, Mich: University Microfilms International, 2001), 43.

Chants pour franchir le seuil (1996-98) through multi-tempo, accelerating and decelerating canonic material in the percussion.

Superficially, tracing these kinds of structures in pitch-time space (the musical staff) reveals similar braided or meandering structures, as occur in stream and river beds (compare figure 3 to 5). One problem with this analogy is that the braided structures revealed by geologic maps of river meanders, or careful examination of an actual river landscape, are traces of *successive* ancient courses of the river, not *simultaneous* rivers.

Figure 6. Satellite imagery of the Mississippi meander belt near Helena, AR. Note the dark-blue oxbow lake that has now been formed where once there was a meander in the earlier image.[25]

However, the presence of these ancient courses is felt in the present moment, particularly in the qualities of the landscape, such as oxbow lakes in various states of evolution toward marshland, and this effect is amplified in a geological map (figure 5).

25 *Helena-West Helena*. October 15, 2014. 34°18'54.24” N., 90°35'32.23” W., Eye Alt. 38.37 mi. Google Earth (May 20, 2015).

In fact, I would go so far as to say that successive and simultaneous phenomena related to river meanders are perceptually blurred – it is almost as if the traces of ancient courses are an echo, or *reverberation of the past of the river.* Indeed, if canons have any direct analogy to acoustic phenomena, it is through echo. Again, I have not attempted to apply river formation models to music, but the similarities are there in retrospect – I am attracted to landscapes, and music, that reveal a history of principled processes inscribed upon them in some way, and I enjoy the mental task of unravelling that history.

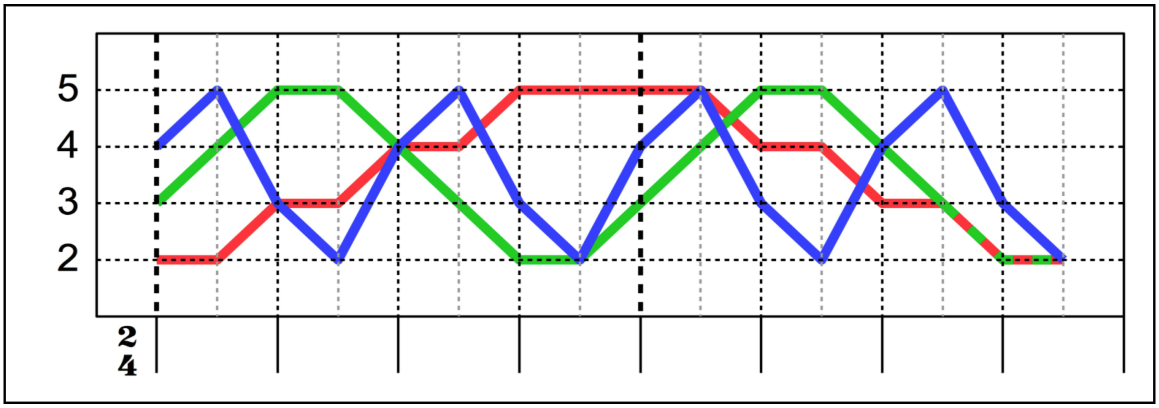

Figure 7. Three layers of quantized tempo variations over the course of eight 2/4 bars.

In the first and third movements of the acoustic music for *Ouroboros*, the primary material was created by braiding together three instances of the same melody, each at a different tempo. Furthermore, each melodic layer changes tempo in accelerating and decelerating waves. An example of these waves is depicted in figure 7. The gradations on the vertical axis are divisions of the beat used (“tuplets”) to realize these tempo variations in a quantized manner, while passing time in measures is depicted on the horizontal axis.

Figure 8. A musical realization of the quantized tempo variation graph in figure 7.

This produces a scaffolding of pulses that is used as a starting point for composing these canons (figure 8). Despite the variability of this scaffolding, there are exactly fifty-six pulses in every voice. In other words, the volume under each of the tempo curves in figure 7, when sampled at the vertical lines, is exactly the same. Thus, any strict canonic activity taking place based on this scaffolding will diverge at the beginning and converge by the end.

Figure 9. Filtration process of the tempo scaffolding used to create canonic rhythmic organization.

The scaffolding from figure 8 is filtered, or eroded, by tying together pulses, as shown in figure 9. A short-range process organizes these pulses into asymmetrical "long-short-long-long-short" groupings using Fibonacci numbers (numbers below the staff). A long-range process creates an acceleration by reducing the number of pulses in each of these groups, again using Fibonacci numbers (numbers above the staff). This process is exactly the same for each voice. The long-short-long-long-short rhythmic motive is retained, relatively, in each group and at each level of the acceleration until the acceleration reaches the grain of the pulses (and the motive is quantized out of existence).

Figure 10. Resulting rhythms after the filtration process.

The result of the filtration process, in simplified notation (without ties) in figure 10, leaves a generally accelerating and then decelerating, canonic rhythmic structure that has internal accelerations within in each canonic voice. Where the filtration process used the largest groupings (three or five original pulses tied together), the original tempo fluctuations have been mostly eroded away. Where the filtration process used the smallest groupings (single pulses), the original tempo fluctuations are left unharmed. The remaining musical surface bears the inscriptions of several successive, principled processes, much like meander belts and glacial cirques. Other processes, such as those detailed in figure 4, would be used to create pitch contours. Though this exact instance of this kind of process isn't used in *Ouroboros*, it is essentially a scale model of the processes used in the first and third movements.

1.2 *Apocryphal Chrysopoeia:* A Synesthetic Virtual Instrument

While my acoustic music has frequently been shaped by processes that might be metaphorically similar to processes found in nature, in my electronic music I often explicitly use computer simulations with parallels to natural phenomena. One set of models, cellular automata, were initially attractive to me because of the diversity and organic character of the behaviors they exhibited, while still being principled, deterministic systems. I used cellular automata, paired with psychological models of equal-tempered pitch perception, as the core components of *Apocryphal Chrysopoeia,* a generative, synesthetic, virtual instrument that allows a computer music performer to explore a space of light and sound simultaneously. This instrument was used to generate the fixed digital audio-visual media components of *Ouroboros,* and is also performed as a stand alone improvisatory work. *Apocryphal Chrysopoeia* was implemented in MAX 6,[26] and representative patches of this implementation can be found in Appendix A.

A columnar structure of forty-eight audio-visual modules, represented visually by

26 Miller Puckette and David Zicarelli, et al., *MAX 6,* computer program (Walnut, CA / Paris: Cycling '74 / IRCAM, 2014).

light-producing geometric primitives and sonically by the voices of a polyphonic synthesizer, forms the conceptual core of this virtual instrument. This column of forty-eight modules, or cells, provides a structured resource of potential sound and light that is temporally articulated by a cellular automaton. In other words, the cellular automaton "plays" what would otherwise be a silent and dark structure of cells. A variety of other sonic and visual manipulations of this structure are also available to the performer.

1.2.1 Cellular Automata and Music: Background

Cellular automata (hereafter abbreviated as CA) are discrete systems whose behavior is completely specified in terms of a local relation;[27] their large scale behavior is thus emergent from small scale interactions. Important contributors to CA theory include John von Neumann (1903 – 1957) and Stanislaw Ulam (1909 – 1984) in the 1950's, John Conway (b. 1937) in the 1970's, and Stephen Wolfram (b. 1959) in his *A New Kind of Science* (2002).[28] For a detailed introduction to the topic of CA, I recommend Tommaso Toffoli (b. 1943) & Norman Margolus' (b. 1955) *Cellular Automata Machines* (1985) and particularly Joel Schiff's *Cellular Automata* (2008).

CA usually operate on a uniform grid of cells in some number of dimensions. Most research on CA has involved one- or two-dimensional CA, and higher dimensional CA can be modeled, though they are more computationally expensive. Each cell has a number of states, in the simplest case, just two. Metaphors for these states include active and inactive, on or off, and living or dead, but typically integers are used to represent

27 Tommaso Toffoli and Norman Margolus, *Cellular Automata Machines* (Cambridge, MA: MIT Press, 1985), 5.
28 Joel Schiff, *Cellular Automata* (Hoboken, NJ: John Wiley & Sons, 2008), xi.

these states. CA are typically modeled in discrete time steps, where updating occurs in unison among all cells (synchronous updating). Asynchronous updating can also be used, and in fact may be more applicable in modeling physical or chemical behaviors.[29] Each cell calculates its state in a new time-step, or turn, based on its state and those of its neighbors in the current time-step, using a transition function, or ruleset.

An example of a transition function can be found in John Conway's *Game of Life* (1970), which uses a two-dimensional lattice of square cells, each with eight adjacent neighbors. In the *Game of Life*, inactive cells become active on the next time-step if they currently have three active neighbors, while active cells stay active if they currently have either two or three active neighbors.[30] All other neighborhood configurations result in cells staying inactive, or turning inactive. As a metaphor for life and death, inactivity in the *Game of Life* thus occurs when cells have too few neighbors to spawn or stay active (death by loneliness), and when cells have too many neighbors to spawn or stay active (death by overcrowding).

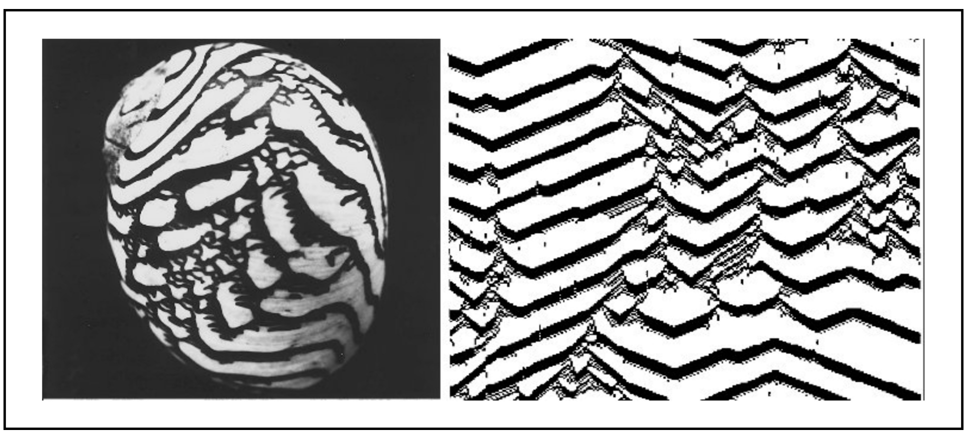

Figure 11: Pigments in a mollusk shell, real and simulated with CA.[31]

29 Schiff, *Cellular Automata*, 118-120.
30 Ibid., 94.
31 Ingo Kusch and Mario Markus, “Mollusc Shell Pigmentation: Cellular Automaton Simulations and Evidence for Undecidability,” *Journal of Theoretical Biology* 178, no. 3 (1996): 333.

CA are appealing aesthetically because they are to be able to create patterns similar to those found in nature, particularly those that involve incremental growth along lattices, such as sea shells and crystals.[32]

In music, Iannis Xenakis was one of the first composers to use CA as a generative process. He mentions the use of CA in *Ata* (1987) and *Horos* (1986), in the introduction to the Pendragon edition of his book *Formalized Music* (1992), although he did not specify which CA he used, or how: “Another approach to the mystery of sounds is the use of cellular automata... It is on the basis of sieves that cellular automata can be useful in harmonic progressions which create new and rich timbric fusions with orchestral instruments.”[33]

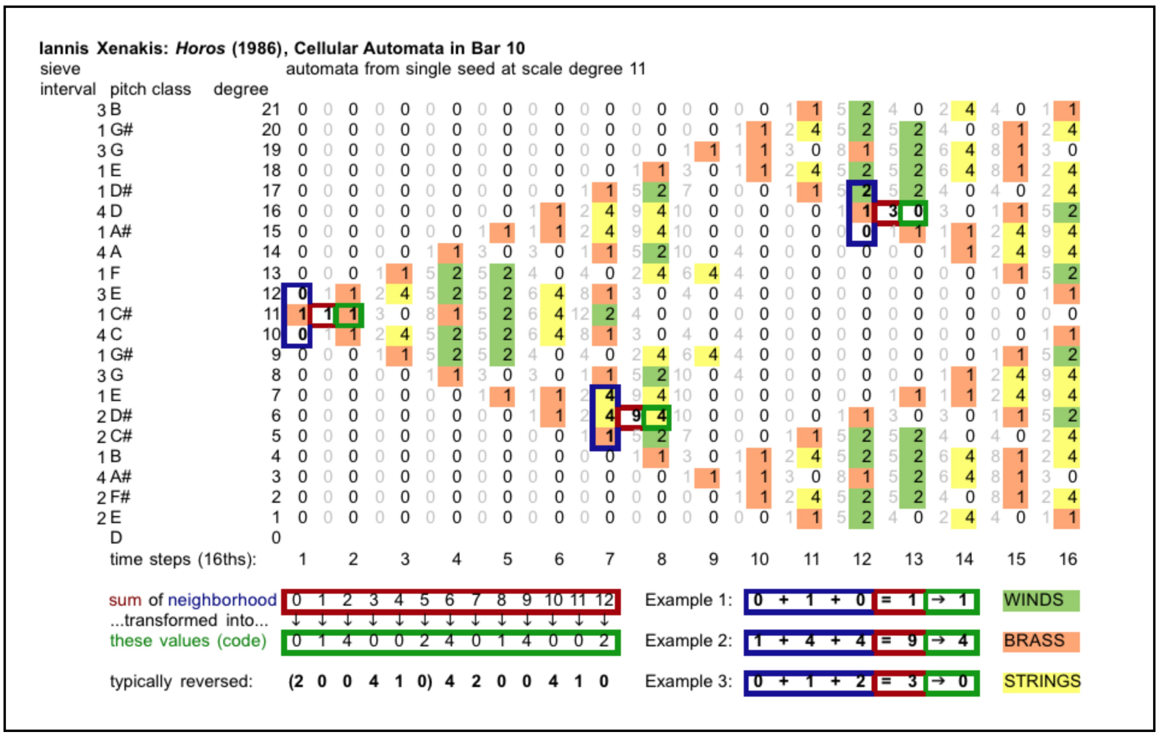

Figure 12. A graphic depiction of the evolution of the cellular automata in bar 10 of *Horos*.

32 Schiff, *Cellular Automata*, 150-155, 157-162.
33 Xenakis, *Formalized Music*, xii.

Xenakis researcher Makis Solomos (b. 1962) connected Stephen Wolfram's article "Computer Software in Science and Mathematics," published in the August 1984 edition of *Scientific American,*[34] with *Horos*, while researching the piece at the Xenakis archives of the *Bibliothèque Nationale de France*. Solomos found that Xenakis used a pocket computer to calculate the successive steps in a one-dimensional, four-state CA detailed in Wolfram's article, based on strips of printed paper in the archives.[35]

Figure 13. Bar 10 of *Horos*.[36]

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34 Stephen Wolfram, "Computer Software in Science and Mathematics," *Scientific American* 251, no. 3 (1984): 188–92, 194, 196–200, 203.

35 Solomos, "Cellular automata in Xenakis's music. Theory and Practice," 9.

36 Ibid., 9.

Xenakis took non-zero cells and mapped those onto note events, using the three non-zero states to decide which instrumental groups were used (winds, brass or strings). Their position along the cellular lattice determined their pitches, using a sieve (in Xenakis' usage, a special type of scale with asymmetrical, non-repeating groups of half- and whole-tones), and the time-steps of the CA determined their placement in a sixteenth-note temporal grid.

This kind of symbolic mapping of the temporal and spatial dimensions of a CA simulation onto music is a fairly normal strategy used by composers working with CA. The space and duration magnitudes used in musical CA typically correspond to the pitch and duration magnitudes commonly found in Western music notation. It is also possible to use much faster update cycles while applying the changing cellular states to sonic dimensions other than pitch, such as directly synthesizing amplitude values in a sound wave. This process would essentially entail the modeling of a system with imaginary physics, something that is quite attractive to me.

In my previous work, *Chemical Oscillator* (2011)[37], I synthesized audio at a duration magnitude somewhere between the extremes of note events and amplitude samples. In that work, I used CA with time-step durations of around 50 milliseconds as a metaphoric representation of the behavior of a chemical system, one that changes the blowing pressure on a set of virtual pipes. As the density of active cells in a portion of the CA changes over time, it changes the blowing pressure on a virtual pipe, exciting different harmonics of that length of pipe. This created a fairly subtle mapping of the visual activity of the CA onto pitch and timbre.

37 Paul Hembree, *Chemical Oscillator* (2011), live digital audio-visual media. https://youtu.be/LtWx7cC85Fs (May 22, 2015).

It is this process of mapping that holds the most dangers to composers working with CA. Gerhard Nierhaus identifies a tendency of composers to use essentially arbitrary and metaphorically weak mappings: "If the specific properties of the applied algorithms [CA] are not suitably used for structure generation, the motivation for selecting them is questionable – these applied algorithms become exchangeable and one runs the risk of generating arbitrary material."[38] I am particularly wary of mappings that treat the spatial dimensions of a CA as multiple types of musical dimensions, for instance, treating the horizontal domain of a two-dimensional CA as rhythmic information while treating the vertical domain as pitch information. In this case, the spatial dimensions of the CA are qualitatively made of the same "stuff," while the musical dimensions are not. Furthermore, though our perception of pitch correlates with a single physical dimension of frequency, our experience of harmony, combinations of pitches, is hardly one-dimensional. Multi-dimensional representations of musical pitch have been my starting point for most of my CA work in the last seven years.

1.2.2 Spatial Metaphors of Pitch and Harmony Perception

A variety of music theory and psychology studies exist that attempt to create spatial models of the perception of pitch and harmony within the common practice style of the Western classical tradition, sometimes referred to as tonal music. Of these, I find that Fred Lerdahl's (b. 1943) book *Tonal Pitch Space* (2001)[39] explicates the most successful theory, and summarizes other attempts well. Lerdahl notes that pitch space theories "are intended to capture the sense of proximity and distance among pitch

38 Gerhard Nierhaus, *Algorithmic Composition* (Dordrecht: Springer, 2009), 202.
39 Fred Lerdahl, *Tonal Pitch Space* (Oxford University Press, 2001).

configurations that listeners bring to bear when hearing tonal pieces."[40] Furthermore, David Lewin (1933 – 2003), Richard Cohn (b. 1955) and Dimitri Tymoczko (b. 1969) have published extensively on Neo-Riemannian music theory, which uses a pitch lattice called the *Tonnetz*, first identified by Leonhard Euler (1707 – 1783), and later developed by music theorist Hugo Riemann (1849 – 1919).[41]

Pitch space theories, looking primarily at tonal music, correlate the experience of relatedness between either individual pitches or harmonies with spatial distances – relatedness in this case is inversely proportional to psychological distance. The psychological distances pitch space theories wish to study are learned through exposure to tonal music. Though the exploration of tonal music with CA was not my goal, having a relatively neutral tonal basis for my virtual instrument was desirable, and was used as a springboard for other explorations with pitch.

I initially chose to work with Roger Shepard's (b. 1929) "double-helix," which attempts to balance the melodic, step-wise proximity of major seconds (two equal-tempered semitones) with the harmonic proximity of fifths (seven semitones).[42] Tiling the surface of this double-helix with cells, each with six neighbors, and wrapping the top onto the bottom in a toroidal fashion, creates a potential space for the spawning of CA. Both dimensions are qualitatively made of the same "stuff" – that is, pitch.

Shepard's double-helix is depicted, unwrapped and flattened onto a two-dimensional surface, in figure 14. Within each pitch-cell, the top number indicates a unique identification number, followed by its note name, and the bottom is its MIDI note

40 Fred Lerdahl, "Tonal Pitch Space". *Music Perception: An Interdisciplinary Journal* 5, no. 3 (1988): 315.
41 Dimitri Tymoczko, "The generalized Tonnetz," *Journal of Music Theory* 56, no. 1 (2012), 10-11.
42 Lerdahl, *Tonal Pitch Space*, 43.

number (where middle C, C4, is 60, and semitones are represented by integers). Dotted pitch-cells show the adjacencies created by the toroidal wrapping.

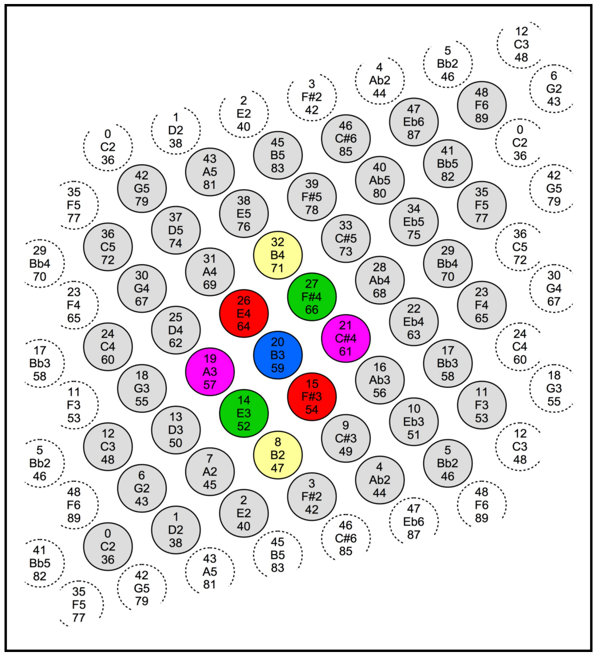

Figure 14. A two-dimensional map of a toroidal pitch space modeled after Roger Shepard's double-helix (Shepard 1982, 316), used in an early version of *Apocryphal Chrysopoeia*.

The coloring here is only used to clarify the harmonic relationships present in the diagrams, not to indicate any pitch-color mappings in the performance of the instrument. The colors show the harmonic relationships within the neighborhood of any cell, in this case, B3, marked in blue. Fourths away from B3 are marked with red, fifths with green, and major seconds with magenta. Light yellow shows octaves, which are outside of the neighborhood, and thus de-emphasized in Shepard's model. After some experimentation, I found that I liked an altered form of the double-helix better (figure 15), and this new altered form is now the default mode of *Apocryphal Chrysopoeia*. The original double-helix was altered by vertically compressing the entire structure. This emphasizes octaves (dark yellow) at the expense of major seconds (light magenta).

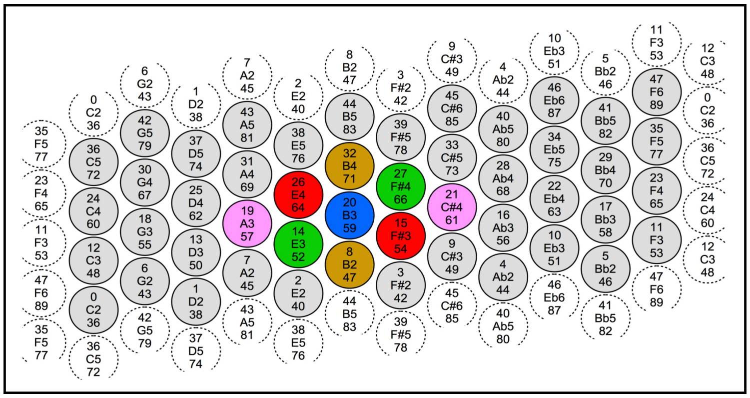

Figure 15. The vertically-compressed double-helix used as the default pitch structure and hexagonal cellular automaton neighborhood in *Apocryphal Chrysopoeia* and *Ouroboros*.

In this new model, harmonic proximity is roughly correlated with spatial proximity. Thus, perfect consonances, such as octaves, fourths and fifths, are represented spatially by short distances, while dissonant intervals such as tritones and minor seconds are represented by long distances. Major seconds are more proximate than minor or major thirds, so tertian harmony is not effectively modeled by proximity in this structure.

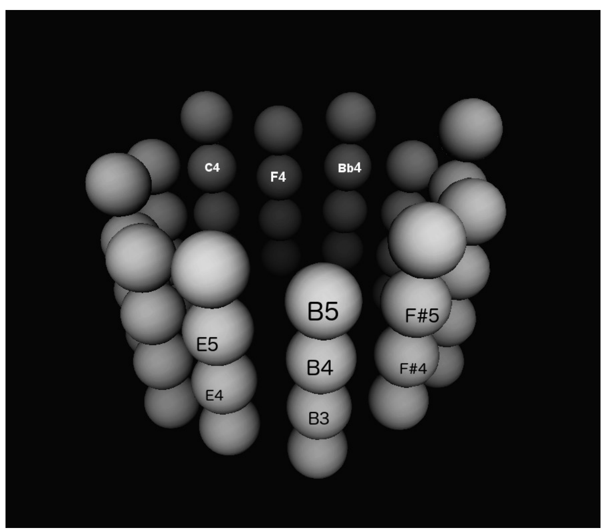

Figure 16. A demonstration still from *Apocryphal Chrysopoeia*, showing the vertically-compressed double-helix.

Figure 16 shows a three-dimensional representation of the structure depicted in figure 15. Black pitch names are provided for several cells (rendered as spheres) in the neighborhood of B4, while white pitch names are for a few cells that are very harmonically and spatially distant from B4. The compressed helix is arranged not as a complete torus, but is instead arranged with only horizontal wrapping, forming a column or cylinder (a true torus would look like a doughnut). Toroidal, top-to-bottom neighborly connections, despite not being arranged as spatially adjacent in the three-dimensional model, are maintained for the purposes of calculating the progression of the CA. In other words, B5's top neighbor, in the calculations of the cellular automaton, is still B2 (unlabelled, below B3).[43]

There was a specific motivation for using a three-dimensional version of the double-helix in conjunction with CA. While the goal was never to model specific styles of music, such as common practice tonal music, I wanted to imbue the CA driven instrument with a very basic musical intelligence. Simple CA, with only adjacent neighbors and short range histories used in their transitions functions, would tend to expand over an entire two-dimensional surface, exciting too many pitches at once to be plausible musically. I did not feel that it was worth it to create CA with huge neighborhoods and complex, history based transition functions, in order to reduce their overall density. Instead, I decided to use relatively simple CA, but on a curved surface that could be rotated, allowing the observer to isolate portions of the double-helix perceptually, creating harmonic fields of potential pitches, using spatial audio.

To do so, I render the light and sound producing modules, cells, in *Apocryphal Chrysopoeia* as if they were in a physical space: distant cells sound quieter, while closer cells sound louder.

43 The patches with the look-up functions necessary to find the neighbors of a cell in this toroidal double-helix are found in the appendix, figures 70 – 75.

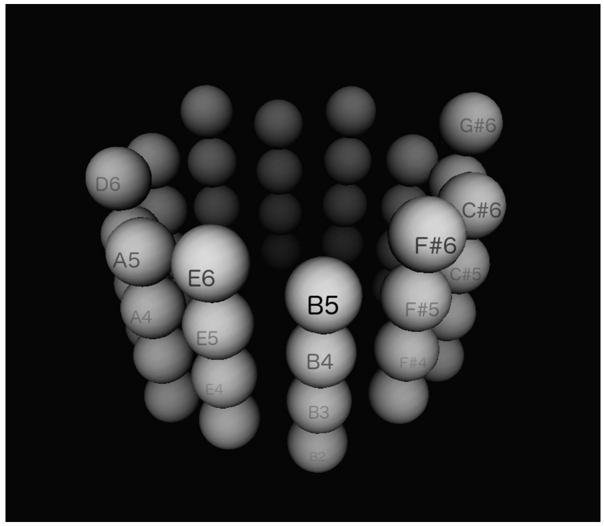

Figure 17. A demonstration still from *Apocryphal Chrysopoeia,* with some pitches labelled .[44]

Similarly, a visual fog thickens and obscures cells as they get further from the observer. The rate at which this audio-visual attenuation occurs is a function of distance, and can be controlled using a parameter called *distance fade* (shortened to *distFade* in the patch; please see the Appendix to see the programing of *Apocryphal Chrysopoeia*). Whatever cells are nearest the observer strongly influence the pitches available in the harmonic field, and as the array of cells changes shape or rotates, the harmonic field modulates as new pitch-classes are introduced. Again, this harmonic field is a structured resource of *potential* pitches, requiring the cellular automaton to articulate them.

An example of the harmonic field in figure 17 is notated on a grand staff in figure 18. Note that B5 is the loudest, and darkest, while B2 is the quietest and lightest. This is a good visual representation of a diatonic harmonic field typically encountered using the standard circle-of-fifths allocation of pitches, conforming to an A major scale, although it would likely be heard as a B dorian scale due to the prominent position (both in loudness

44 In my current model, volume is slightly more sensitive to distance than visual rendering, and therefore we can see more cells than we can hear. This is to reduce the density of events in the audio domain, which seems to be more susceptible to perceptual masking.

and number of octaves represented) of that pitch-class.

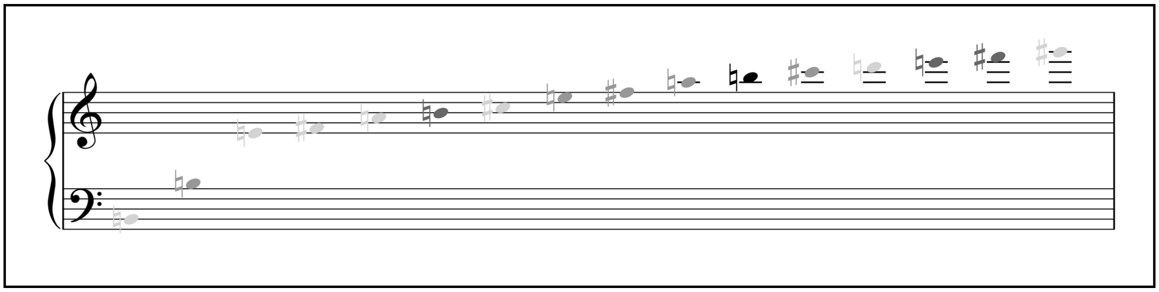

Figure 18. A list of the pitches present in figure 16, shaded according to volume based on proximity to the observer.

In fact, observer proximity to the virtual sound emitting sources, used as a determinant of harmonic content, is a more powerful tool, with richer implications, than the double-helical arrangement of the circle of fifths, used as the default pitch space. Though the double-helical arrangement was the initial inspiration for using observer proximity to determine amplitude, it has proved less fruitful as a compositional tool because I find rotation through the familiar keys of diatonic music to be too perceptually smooth.

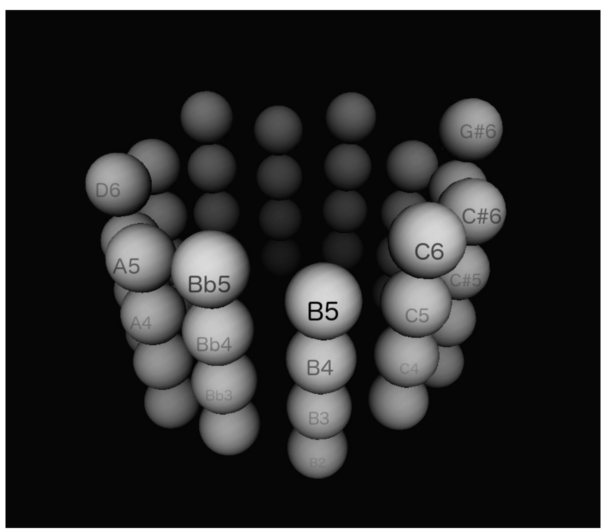

Figure 19. A demonstration still generated by *Apocryphal Chrysopoeia*, similar to figure 16, but with two pitch-class swaps: Bb has been swapped for E, and C has been swapped with F#.

This reliance on rotation could be avoided by allowing teleportation (instantaneous displacement in location), but the programming implications of smoothly crossfading between locations during a teleport proved to be too difficult.

In *Ouroboros*, and usually in most stand alone performances of *Apocryphal Chrysopoeia*, I do not use the standard circle-of-fifths arrangement, but instead swap pitch-classes with each other (see figure 19) in order to do two things: create more dissonant harmonic content, and to create changing qualities in harmonic content depending on the rotation of the column of cells. The circle-of-fifths allocation results in every face of the column sounding uniform – every face results in the same, diatonic arrangement of possible intervals, although they are transposed depending on which face is nearby. Swapping pitches introduces asymmetries that then result in different collections of intervals for every face of the column. Rotation then creates not only modulation of key center, but also modulation of modality, giving different faces of the column different harmonic characters (see figure 20).

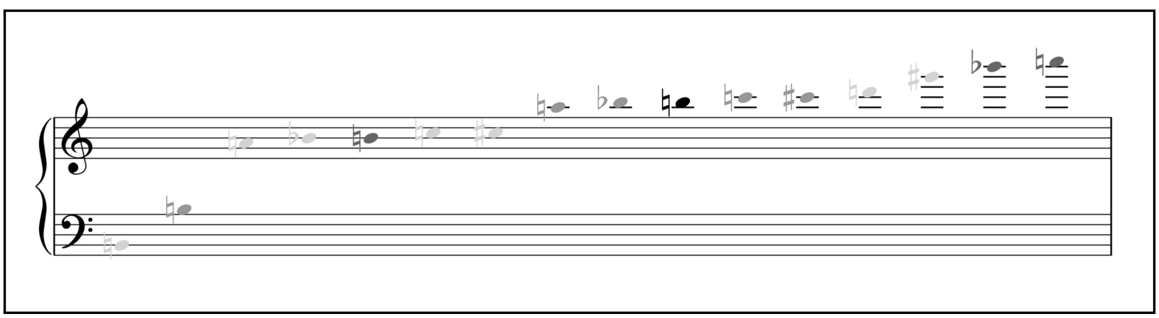

Figure 20. The harmonic field resulting from the allocation of pitches shown in figure 18. Note the inclusion of many more possible dissonances due to the presence of Bb and C.

Either the *pitch phase* (*pitPhase*) or *rotation duration* (*rotDur*) variable controls rotation of the column, depending on the needs of the musical context. *Rotation duration* is used in solo improvisations, while *pitch phase* is used when the electronics play as part of an ensemble, in order to lock the harmonic field of the instruments to the harmonic field of the electronic sound. This technique was used extensively in the second and third movements of *Ouroboros*.

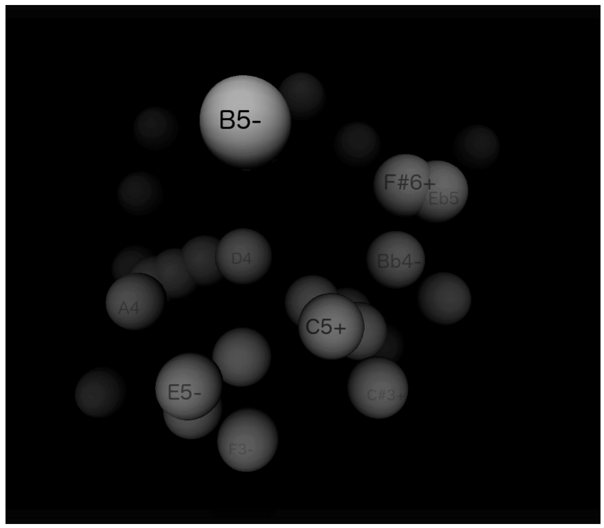

Figure 21. A highly scattered arrangement of cells due to a very active *wander* function. Detuning is suggested by plus and minus signs.

In addition to swapping equal-tempered pitch classes, a *wander* function allows me to scatter the entire structure apart. This scattering effect randomly detunes the synthesizer voices for each cell, within the range of a half-step, above or below (see figure 21). This detuning, combined with the random spatial arrangement of cells, allows for even more unpredictable encounters with various pitch-classes, creating both atonal and microtonal harmonic fields (see figure 22). I usually find myself using a *wander* parameter between 10% and 25%, with a maximum (at 100%) of an eighth-tone deviation, to add macroscopic pitch and spatial variation to the instrument.

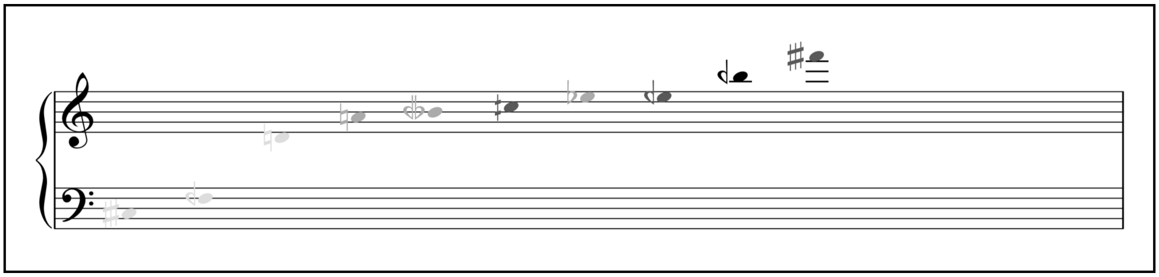

Figure 22. A harmonic field created by arrangement of cells in figure 20. Detuning here is notated with standard quarter-tone accidentals.

1.2.3 Articulating the Pitch Space

The columnar structure of cells, which might be thought of as the basic "instrument" of *Apocryphal Chrysopoeia*, is activated (or "played") by a two-dimensional, hexagonal CA wrapped onto the three-dimensional columnar structure. As mentioned earlier, CA are used in other contexts to mathematically model the propagation of patterns across lattices. In this context, CA were chosen because of their ability to evolve in a dynamic and variegated fashion across space in a way that resembles, but is not identical to, musical voice-leading. This resemblance primarily depends on the apparent connections between successive events. Cellular activity propagates by the activation of one or more cells within a neighborhood of adjacent cells, and it is this activation within boundaries that is analogous to the closest-motion rule of voice-leading.

Eight steps in a toroidal, hexagonal CA with the transition function "23/34" are shown in figure 23. The shorthand "23/34" means that inactive cells (grey) activate on the next time-step if they currently have two or three active neighbors, and active cells (blue) stay active on the next time-step if they currently have three or four active neighbors.

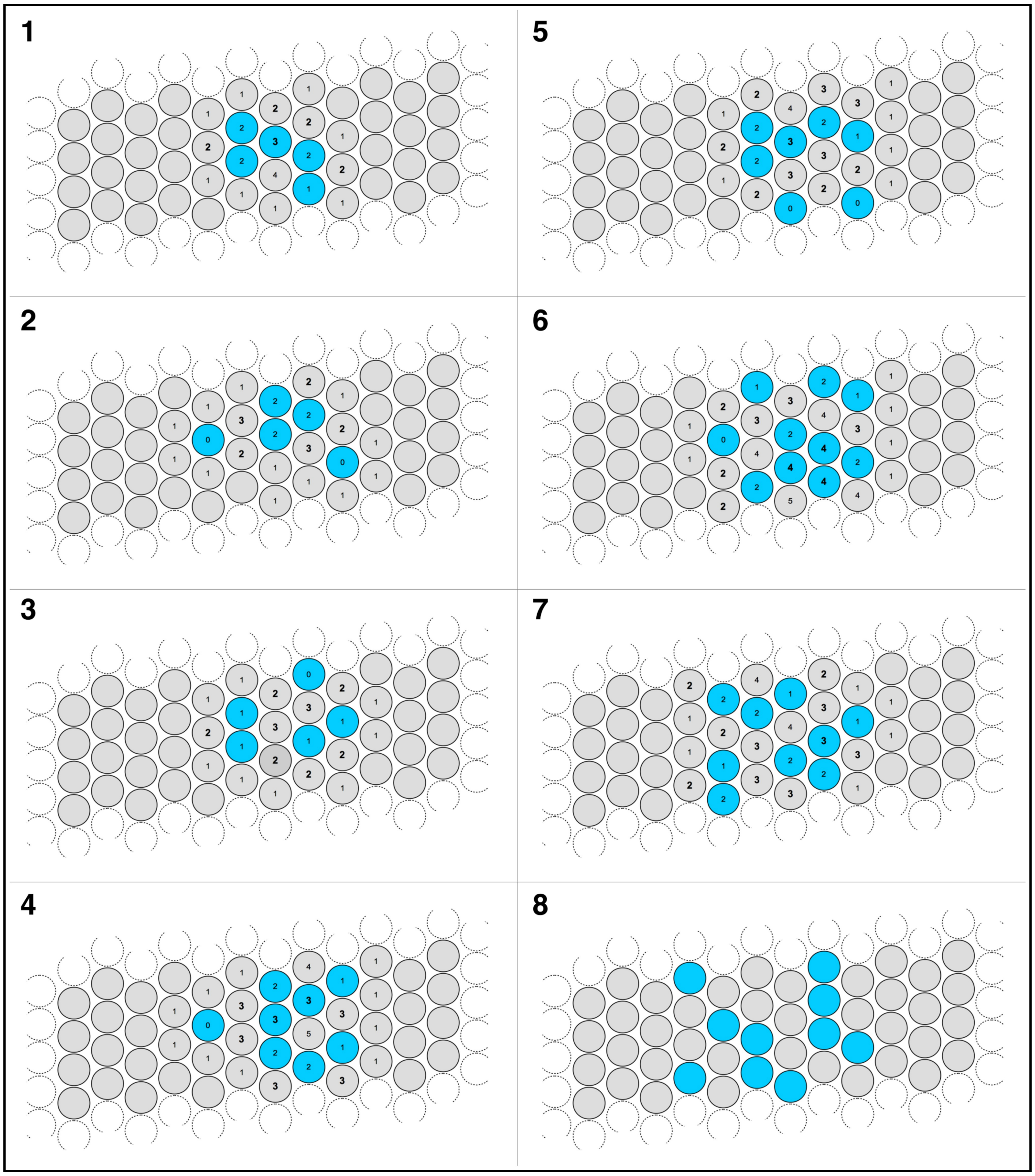

Figure 23. Eight steps in a toroidal, double-helical, hexagonal cellular automaton with the ruleset "23/34."

Numbers within each cell indicate the number of active neighbors; bold numbers indicate which cells will activate or stay active on the next time-step due to the transition function. Cells not near enough to participate in the activity are left blank, but would otherwise have a zero to indicate they have no active neighbors and are currently inactive. Figure 24 is the same as figure 23, but with unique identification numbers, pitch names and MIDI note numbers for all of the cells.

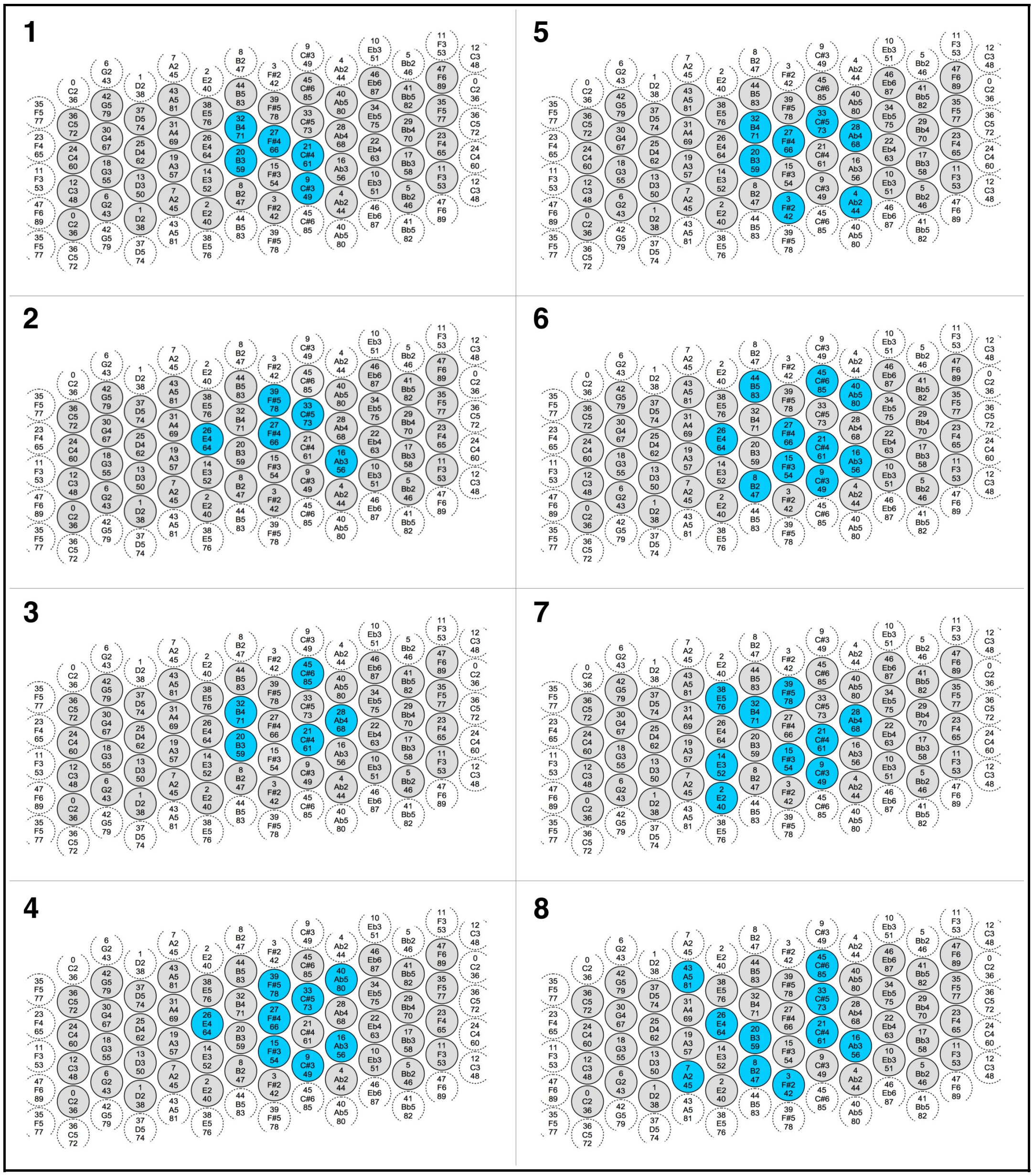

Figure 24. The same cellular automaton steps as figure 22, but with the same labelling as figure 15, showing some information about pitch.

Frequently I choose the transition function "23/34" in the hexagonal cellular automata used in *Apocryphal Chrysopoeia*. This transition function can be left to play continuously on its own, in the toroidal space, without becoming too dense or too thin. I hypothesize that activity produced by this cellular automaton would grow infinitely in all directions, but because it is constrained to a forty-eight cell torus, it simply refreshes itself continually.

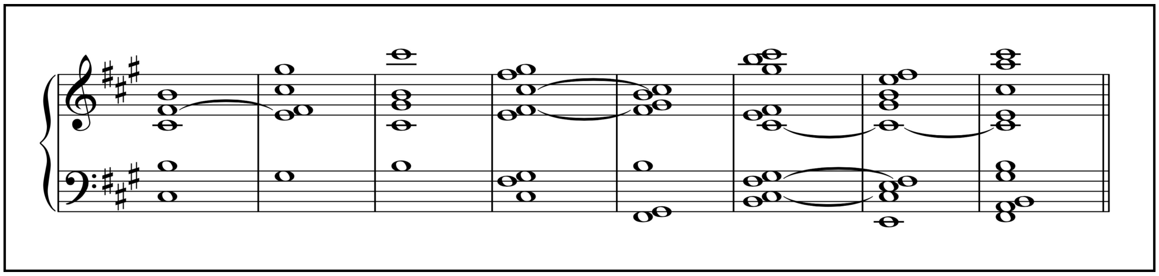

Figure 25. The progression generated by the eight steps in the cellular automaton and pitch mapping in figure 24.

The progression generated by the eight steps in this CA, with this pitch-mapping, is shown in figure 25. The region of the pitch space excited in figure 24 constrains the available pitches to the A major scale (or B dorian mode), and hence a key signature is used in this figure. This constraint to the A major scale is not a result of any amplitude adjustment due to distance, but is simply the result of which cells became activated after the initial conditions.[45] Cells that stay active are not re-articulated, and thus are tied to. This pitch progression certainly does not resemble the voice-leading found in tonal music: the number of implied voices is not held constant, and the motion of what voices are implied incorporates too many leaps.

As detailed earlier, activity in the CA propagates through adjacent cells. This process, combined with a pitch map that correlates harmonic proximity with spatial proximity creates implied voice-leading between adjacent chords that resembles the leaps found in the "harmonic" bass lines of tonal music – but distributed to all implied voices.

45 However, similar results might be produced by amplitude adjustment over distance by hovering over the A-major face of the column, even if cellular activity were spread all over the column.

In other words, if one moves primarily through adjacent cells, and those adjacencies are represented not by steps but by leaps of fourths, fifths and octaves, the resulting voice-leading will primarily be composed of those kinds of leaps.

The high density of leaps is partially mitigated by illusionary motion by steps (for instance, the oscillation of B4 and C5 in the treble staff, figure 25), generated by the successive activation of non-adjacent cells. Swapping pitch-classes in the pitch map can be used to further mitigate the high number of leaps by creating actual step-wise relationships between adjacent cells. A texture with a mix of implied leaps and steps, aided by these pitch-swaps, is useful in generating music-like behavior, in addition to providing more interesting dissonances for the listener.

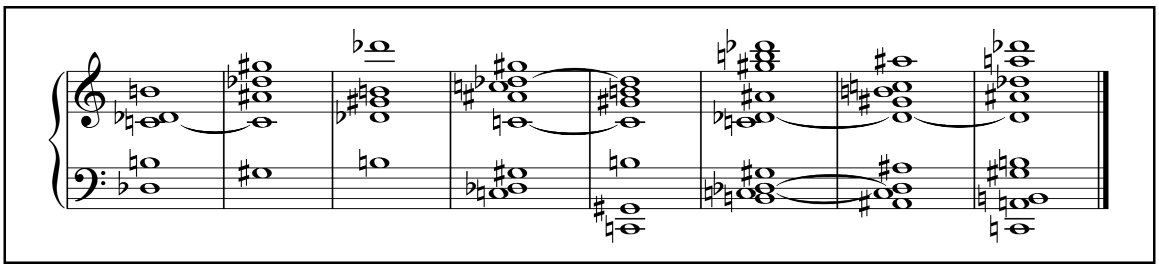

Figure 26. The progression generated by the eight steps in the cellular automaton in figure 24, but with the pitch mapping that swaps C instead of F# and Bb instead of E. Some pitches are respelled for easier notation of harmonies.

Some cellular automata transition functions allow for the evolution of emergent structures: persistent patterns that are the product not of high-level user control, but of local interactions. Although I was initially hoping for more reliance on emergent structures in *Apocryphal Chrysopoeia,* I was dismayed to find that in the constrained space of forty-eight cells that I used, any emergent structures that formed were too simple to be interesting for very long. Long period oscillating structures were extremely rare in transition functions that I explored. Furthermore, in order to accentuate emergent structures, it would be necessary to rely on low *timeJitter* and short *attack* settings, something which brought the occasionally objectionable synthetic character of the wavetable synthesis method to the fore (this is discussed below).

It should be noted that I typically excite the CA by randomly activating about 50% of the cells. I can change this density, but in the current implementation I do not have refined control over exciting small, localized groups of cells. Global excitation, combined with the ability to change the CA transition function, and thus the ability to change the "excitability" of the system, has been enough to create engaging improvisations with the instrument, especially when combined with the ability to spatially reorient the observer's point of view.

1.2.4 Randomized Onsets and Smoothed Edges

Although the core structure and activation method of *Apocryphal Chrysopoeia* are grounded in discrete models or processes, numerous controls allow the performer to bend these rules. The monotonous rhythm of large time-grain CA can be mitigated by using randomized onset delays (*timeJitter*) and smooth attack envelopes (*attack*).

There are two modes of onset delay built into this instrument, both controlled by the *timeJitter* variable. The first and most basic randomly delays the onset of each synthesizer attack and brightness change in each geometric primitive by some percentage of the duration of each time-step. A more nuanced, second mode for time *timeJitter* randomly delays each onset by a random amount with increasingly fine quantization of the duration of each time-step. This quantized, random onset delay ranges from dividing the time-step into two parts to sixty-four parts. If each time-step is thought of as a quarter note, then those delays range from eighth note syncopations up to 256th-note syncopations – at which point the time grain is felt as continuous rather than quantized. It should be noted that the CA calculations are unaffected by these time delays, and remain synchronous. CA with asynchronous updating do not have the same predicable character of those with synchronous updating: "cyclic dynamics can only occur with synchronous updating... in addition, various patterns formed in synchronous updating are absent with asynchronous updating."[46]

Rounding off the corners of the attacks further softens the hard-edges of turn-based CA. In *Apocryphal Chrysopoeia*, the duration of the attack portion of each synthesizer amplitude envelope and brightness change in each primitive is controlled by the *attack* variable. At its lowest setting, the *attack* takes 5% of the time-step duration to rise, which is a safe low threshold to prevent noticeable "popping" in the audio. At its highest setting, the attack takes the entire duration of each time-step to rise. There is also a *decay*[47] variable which does the same thing in reverse, controlling how long it takes a cell to decrease in amplitude and brightness to zero. It should be noted that a high *decay* setting causes the harmony generated on one time-step to bleed into the next, which is compounded by reverberation (discussed later) as well. An additional amplitude control is implemented to prevent long-lived cells from becoming too dominant in the audio-visual texture. A cell's audio-visual amplitude is inversely proportion to its age, and the duration of this change is controlled by the *attack* variable.

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46 Schiff, *Cellular Automata*, 118-119.

47 This might have been better called release, which is a more common way of referring to the last stage in amplitude envelopes in synthesizer design.

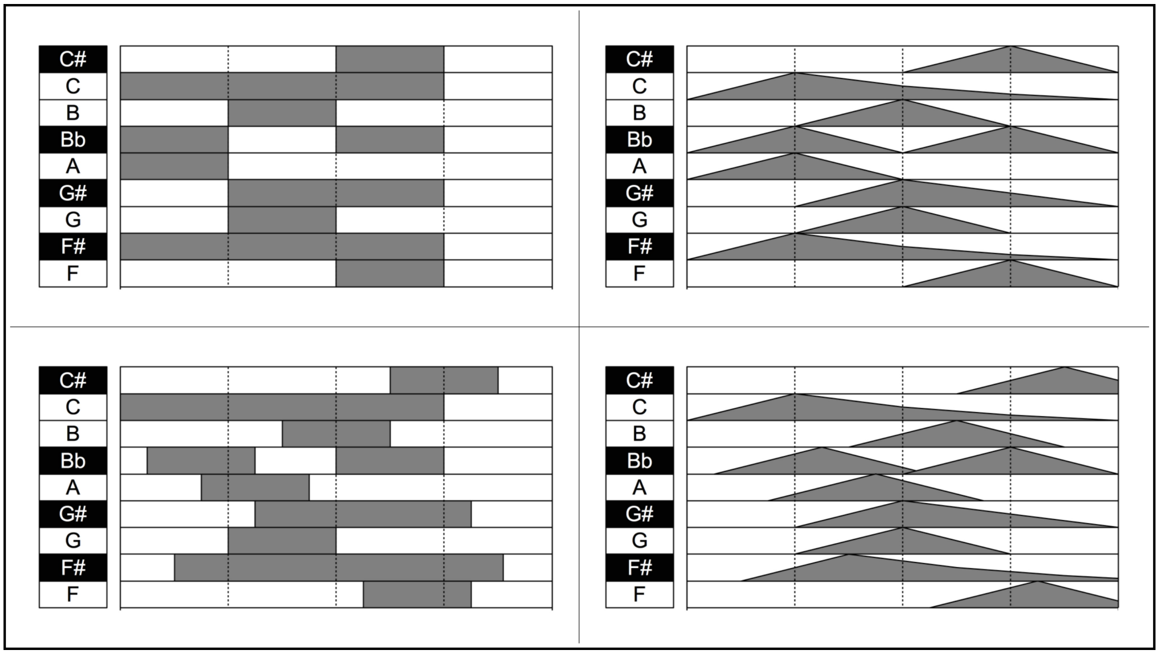

Figure 27. "Piano-roll" style notation for four different onset and amplitude envelope regimes.

The cumulative effects of various amplitude and onset controls are depicted in figure 27. Pitch is on the vertical axis (in "piano roll" style) while time, marked with CA update cycles as dotted lines, is on the horizontal axis. Within each pitch track, the block of grey depicts the amplitude of that pitch. The pitch-time content is hypothetical, and is not based upon any particular CA. Both regimes on top of figure 27 both have no randomized onset delay (no *timeJitter*), and both bottom regimes have randomized onset delays quantized to four divisions of the time-step (a low but noticeable *timeJitter*). The left regimes have no amplitude envelope adjustments, while the right regimes have *attack* and *decay* durations lasting entire time-steps, with additional attenuation by age. With moderate to high *timeJitter*, *attack* and *decay* settings, the "blocky" character of the turn-based cellular automata can be completely mitigated (compare the top left to the bottom right in figure 27). Furthermore, these settings also assist in smoothing out the occasionally "leapy" character of the voice-leading: abrupt changes in register sound much more atmospheric when the attacks are de-correlated and gradual.

An alternative way to mitigate the blocky character of CA would be to use floating point states instead of binary states, controlling a number of possible sonic dimensions relatively continuously. Christopher Ariza detailed ways to do this with one-dimensional CA in his 2007 *Computer Music Journal* article "Automata Bending."[48]

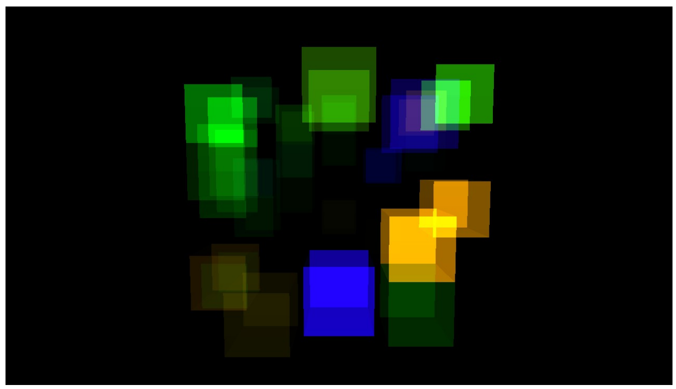

Figure 28. *Apocryphal Chrysopoeia* without any cross-modal effects. Cubes are the default geometric primitive because their individual rotations, controlled by the *skitter* variable, are easy to see.

1.2.5 Visual Music: Background

There are numerous textural and timbral cross-modal mappings used in *Apocryphal Chrysopoeia*. The goal has been to create quasi-physical visual behaviors that, when linked with sound, have an unmistakable believability. I am searching for *synchresis*, "the spontaneous and irresistible weld produced between a particular auditory phenomenon and visual phenomenon when they occur at the same time."[49] However, because of the profusion of different interconnected dimensions that are manipulated

48 Christopher Ariza, "Automata Bending: Applications of Dynamic Mutation and Dynamic Rules in Modular One-Dimensional Cellular Automata," *Computer Music Journal* 31, no. 1 (2007), 29–49.

49 Michel Chion, Claudia Gorbman, and Walter Murch. *Audio-vision: sound on screen* (New York: Columbia University Press, 1994), 63.

simultaneously, the audio-visual experience is never didactic nor cartoonishly mimetic. My inspiration for these cross-modal mappings comes from the visual music tradition.

Visual music is not usually described as a coherent aesthetic movement, but rather a common thread involving synesthetia that runs through various types of abstract static and time-based visual art in the twentieth and twenty-first centuries. A musical inspiration behind that abstraction is the uniting feature:

> [Visual music works are] audiovisual creations in which the artist strives to endow the video component with formal and abstract qualities that mimic those of musical composition. This emulation often, but not necessarily, derives from a more or less direct mapping between sonic elements in the soundtrack, on the one hand, and time-varying visual parameters in the video track, on the other.[50]

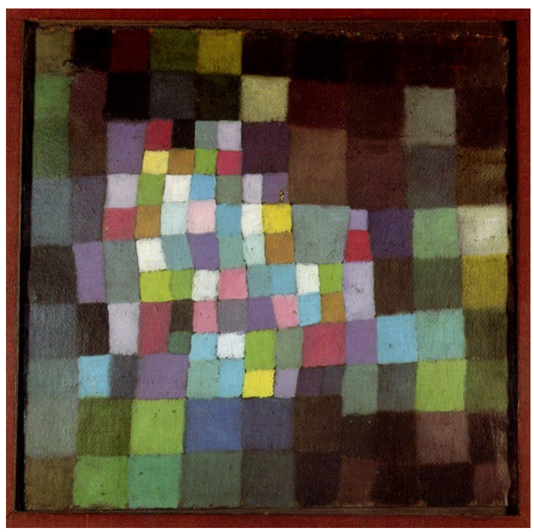

Figure 29. Paul Klee, *Abstraction with Reference to a Flowering Tree* (1925).

This synesthetic thread runs through abstract painting, instrument creation, avant-garde film and music, up to recent works in installation and digital intermedia arts. I am most interested in time-based visual music, but it is important to note that some of the roots of abstract static art in the twentieth century often can be found in art that aspired to

50 Douglas Keislar, “About This Issue,” *Computer Music Journal* 29, no. 4 (December 1, 2005), 1.

the condition of music, by artists including Wassily Kandinsky (1866 – 1944), Paul Klee (1879 – 1940), Arthur Dove (1880 – 1946), and Helen Torr (1886 – 1967).[51]

Time-based visual music is often divided into two categories, of which the oldest is sometimes called "color music," or "color organ music." Its background lies in performances involving light projecting "organs" invented by a variety of people since at least the early eighteenth century.[52] Indeed, music influenced color theory since Isaac Newton's (1642 – 1727) first experiments between 1666 and 1704. Newton was quite convinced that musical scales and color were connected – so much so, that he identified seven colors in the rainbow, modeled after the seven diatonic scale pitches in contemporaneous Western music, failing to notice that there are in fact six dominant colors in the rainbow.[53] Idiosyncratic color-pitch mappings have been extremely common over the centuries, but it is extremely unlikely there is any universal, physiological connection between the perception of specific frequencies of air-pressure fluctuations with specific frequencies in the electromagnetic spectrum. I have avoided color-pitch mappings in my CA works, although it would be plausible to create perceptible, but ultimately arbitrary connections in this domain.

Though many organs were used in public performance, none produced light and sound simultaneously through the same equipment. However, they could be used simultaneously with other sound sources, for instance, as with Preston S. Millar's (ca. 1880 – 1949) *chromola* during the 1915 New York premiere of Alexander Scriabin's (1872 – 1915) *Prométhée* (1908-10). Many color organ creators, including Claude

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51 Kerry Brougher et al., *Visual Music: Synaesthesia in Art and Music Since 1900* (London: Thames & Hudson, 2005), 15-20.
52 Brougher et al., *Visual Music*, 70.
53 Ibid., 213.

Bragdon (1866 – 1946) and Thomas Wilfred (1889 – 1968), did not believe there were any artistically appropriate physical correspondences between sound and light. Others, such as Mary Hallock Greenewalt (1871 – 1950), created connections between sound and light as an interpretive activity, without an explicit algorithm. "Her approach was not an intrinsic or quantitative mapping of music to light... [her] "mapping" is tantalizing to the contemporary reader, as it evokes an algorithmic process, [but] her mapping is a composition in its own right, a companion to Debussy's."[54] (Wright 2011, 4-5). I prefer to think of the design of my audio-visual algorithms *as* collections of interpretive decisions that can be deployed via various controls.

Artists working with abstract film and animation, including Oskar Fischinger (1900 – 1967), Len Lye (1901 – 1980), and John (1917 – 1995) and James Whitney (1921 – 1982) connected sound and light more closely than earlier artists working with color organs. I am particularly fond of the Whitney brothers' *Five Film Exercises* (1943-44), despite the dated sound of their synthesis methods, because they effectively merged the creation of both electronic sound and moving images into one activity. They created an optical printer and four octave electro-mechanical instrument, using "pendulums of differing lengths fitted with adjustable weights... attached by a wire to an aperture in the camera which recorded their movements, thereby creating sound from motion."[55] Their translucent combinations of hard-edged shapes on a black background influenced the visual aspects of *Apocrypha Chrysopoeia*.

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54 Maurice Wright, "Nourathar: an early 20th century color organ," in *SEAMUS 2011 conference proceedings* (Miami, FL: 2011), 4-5.
55 Brougher et al., *Visual Music*, 125.

1.2.6 Cross-modal Mapping in *Apocryphal Chrysopoeia*

Working along the same vein as the Whitney brothers, I have sought to merge the activity of producing both sound and light. In *Aprocryphal Chrysopoeia*, the sound production method for each sound and light emitting module, or cell, is a custom dual-wavetable synthesizer.[56] The entire apparatus of modules can be though of as a multitimbral, polyphonic synthesizer with forty-eight voices. The color (hue) for a cell is calculated from the number currently active neighbors – the entire hue space is divided into seven parts, corresponding with zero through six possible active neighbors in the hexagonal CA. This relationship changes continuously by an offset driven with a random walk, ensuring that a variety of colors are seen in a performance. Hue then connects with sampled instrumental timbre: the spectral brightness and density of source waves for the synthesizers is roughly proportional to the warmth of the colors. Thus, waves with bright and dense spectra, taken from bass trombone, violin, and cello are roughly mapped onto red, yellow and magenta, while waves with dark and sparse spectra, taken from flute (in this case, piccolo), vibraphone, harp and clarinet, are roughly mapped onto green, cyan, blue and violet.[57] The relationship between color temperature and sonic spectral character is perceivable, and thus useful as a dimension to explore artistically. Clarinet is also objectively brighter than its cool counterparts, but because of its emphasis on odd harmonics, it seems to fit well onto violet.

Rippling in the surface of the cells connects with a chorusing effect: subtle

56 Each dual-wavetable consists of two separate wavetables that crossfade between each other to produce smooth transitions in timbre. In essence, each module is monotimbral, but with smooth transitions between timbres. The entire instrument can be considered multitimbral.

57 Dividing RGB hue space into seven parts is admittedly problematic. Six divisions would be much more optimal. With seven parts, violin is closer to yellow-orange, and both flute (piccolo) and vibraphone end up with greenish hues.

frequency and amplitude modulation of the wavetable synthesis. This rippling and chorusing, together called *scramble*, partially mitigates the synthetic character of the basic audio and visual rendering techniques (see figure 30).

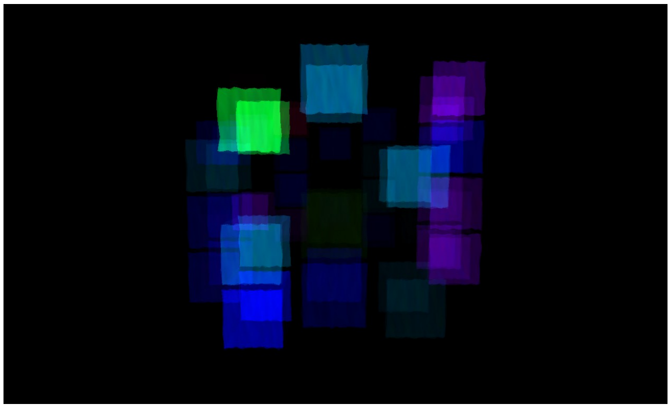

Figure 30. *Scramble* in a low setting causes rippling in the surface of the primitives, along with subtle chorusing in the audio domain.

Like *wander*, I find myself using 10% to 25% *scramble* to add, in this case, microscopic pitch and surface variation in the cells themselves. *Scramble* can also be taken to an extreme, jittering the vertexes of the primitives until their shape can no longer be identified (see figure 31). Similarly, by increasing the depth of fluctuations in the pitch and amplitude of the wavetable synthesizers, the timbre of each cell is obliterated, becoming noise.

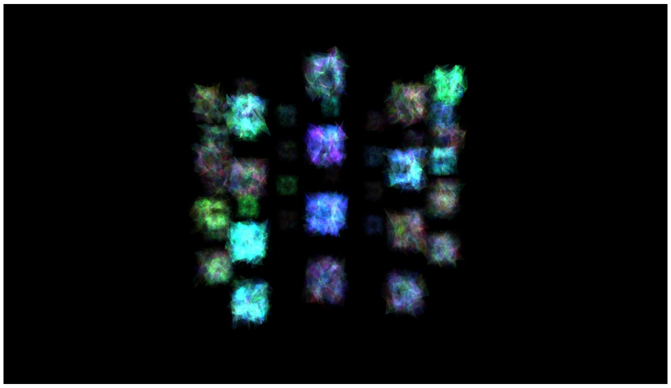

Figure 31. *Scramble* taken to an extreme creates audio-visual noise.

Degrading the fidelity of the three-dimensional models by reducing their polygon count (see figure 32) also degrades the quality of the waveforms, in this case by decimating the sampling rate, introducing aliasing frequencies into the mixture. This effect is called *crush*.

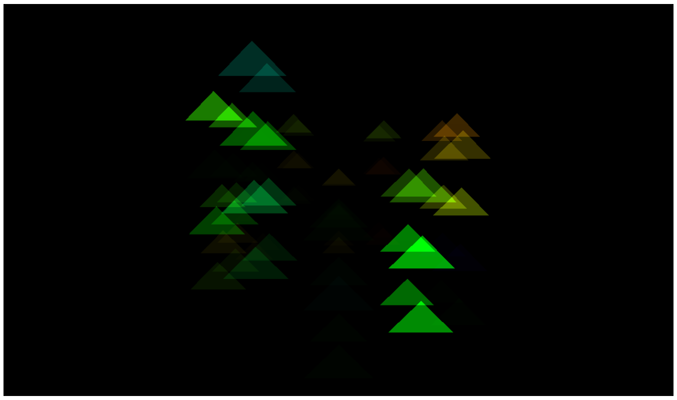

Figure 32. *Crushed* primitives with only two polygons remaining. These would be coupled by extremely decimated audio, with only a few frequencies accurately represented.

Rotation of the primitives in three dimensions can also be driven by random walks (see figure 33), coupled with ring modulation of the wavetable synthesizer by an triangle-wave oscillator.

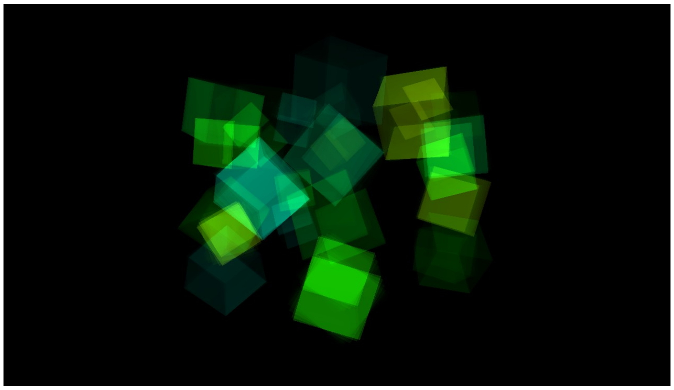

Figure 33. *Skittered* primitives rotate randomly around their respective center points in three dimensions, coupled with randomly "rotating" ring modulation.

Because the primitives rotate around each of their center points, I chose to have the ring modulation “rotate” around the central pitch of each wavetable synthesizer, bounded within a semitone above and below. This creates noticeable beating that constantly changes speed, a behavior that I dubbed *skitter*.

The saturation of color in all the primitives can be reduced, leaving ghostly-white remnants (see figure 34). This same process is mimicked by applying a resonant band-pass filter to the wavetable synthesizers, with a constantly shifting center frequency.

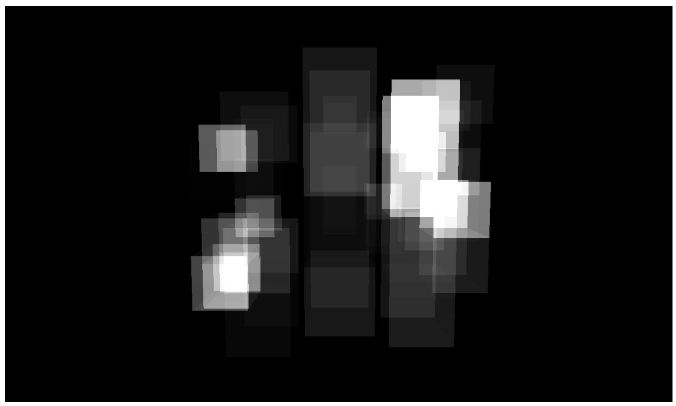

Figure 34. *Spectre* desaturates the primitives, and applies a bounded resonant band-pass filter to the spectra of the sounds.

This creates something strangely reminiscent of Tibetan or Mongolian over-tone singing by resonating one or just a few individual partials of a complex tone, while filtering out the rest of the spectrum. I call this effect *spectre*. This center frequency is bounded between the second and sixteenth harmonic, or between twice and sixteen-times the frequency of the wavetable synthesizer's fundamental.

Reverberation in sound is coupled with visual feedback. Each frame of the animation is only partially erased in successive frames (see figure 34) when reverberation is turned up. This is simply called *wet*.

These cross-modal mappings allow me to explore timbral and textural transformations as a way of providing additional large scale structure for works involving

Apocryphal Chrysopoeia, such as *Ouroboros*. These transformations refresh the audio-visual space in ways that would be difficult with only the cellular automata-driven articulation of various harmonic fields.

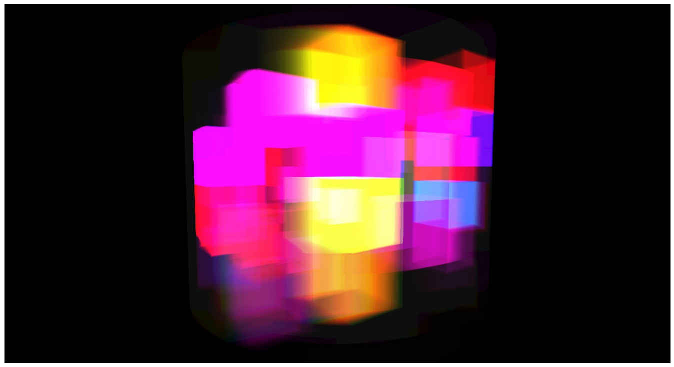

Figure 35. *Wetness* in reverberation is coupled with visual feedback.

1.3 Extended Trumpet Techniques

In movements two and three of *Ouroboros*, the harmonic structure is indebted to the rotation of the columnar structure of cells in the virtual instrument described above (in the first movement, there is not enough overlap of the instruments and electronic sounds for this to be necessary). The acoustic instruments play from a selection of pitches available in the harmonic field afforded by the electronic instrument. In addition to influencing my acoustic music structurally, my electronic music has influenced my acoustic music timbrally. In particular, I have sought to expand the repertoire of timbres available on my native instrument, the trumpet, using distortion-like sounds, reminiscent of the *skitter* (ring-modulation) and *crush* (sampling-rate decimation) effects in the virtual instrument. This melding of electronic and instrumental timbre primarily occurs in the opening of the second movement, which, as a whole, is the trumpet "feature" movement.

Over the past few years, I researched the relatively new terrain of brass split-tone multiphonics as a way to find distortion like sounds. Multiphonics in general are instrumental techniques, first developed on woodwind instruments, that involve the apparent production of more than one fundamental frequency, simultaneously, on a monophonic instrument. Oboist Peter Veale (b. 1959) provides a concise description:

> A single note on [a wind] instrument consists of a large number of partials (along with an inseparable noise component), whose combination makes up the specific timbre of the instrument – its spectrum. … As these partials represent exact multiples of the fundamental note they are heard as a single note. … If the partials do not represent exact multiples of a fundamental frequency, we hear a complex chord which is called a multiphonic.[58]

Bruno Bartolozzi (1911 – 1980) and Reginald Brindle (1917 – 2003) compared the instrumental timbres of multiphonics with electronic timbres in their influential book, *New Sounds for Woodwind* (1967). In brass music, split-tone multiphonics have been more prevalent in the literature for and about the trombone, perhaps because its larger mouthpiece more easily allows for two side-by-side buzz-points to form on the lips (see below). Stuart Dempster's (b. 1936) book *The Modern Trombone* (1979) provides a good description of the technique, along with a method of learning how to produce it with regularity:

> The split tone is another effect that clutters the texture. It is just what the name implies: a split – in this case, between two partials so that elements of both partials are heard. This is a means of producing multiple sounds – a “multidivider” - not by using the voice, but by the lips breaking up into two embouchures. ... The performer must hunt for the balance point between the two partials; this can be heard, or more properly perhaps, felt. One way to learn this technique is to lip slur back and forth on the two partials, slowing down until the balance point is found.[59]

58 Peter Veale and Claus-Steffen Mahnkopf, *The techniques of oboe playing: a compendium with additional remarks on the whole oboe family*. (Kassel: Bärenreiter, 1998), 69.
59 Stuart Dempster, *The modern trombone: a definition of its idioms.* (Berkeley: University of California

Harold Lloyd Leno's (1925 – 1998) dissertation[60] features high-speed video of Dempster's lips during the production of split-tone multiphonics, revealing that there are indeed two, side-by-side buzz-points involved in the production of these sounds. Each buzz-point oscillates at a different frequency, and each seems to excite a different harmonic of the air column within the instrument.

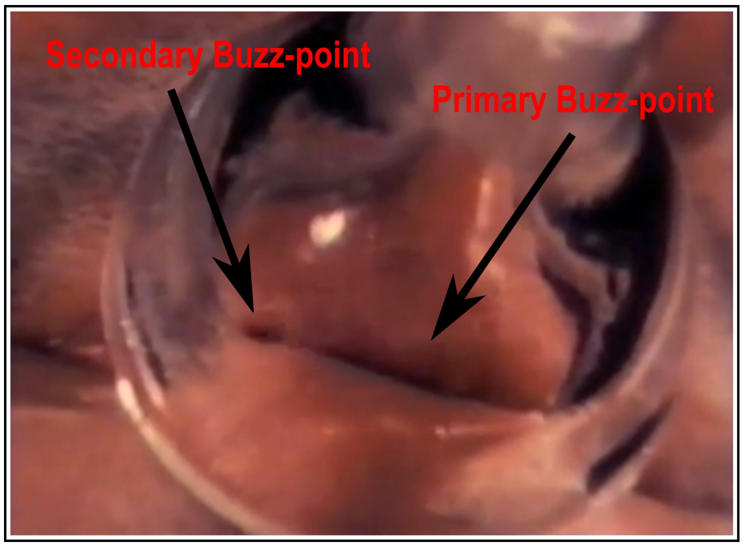

Figure 36. Dempster producing a split-tone multiphonic; buzz-points marked.[61]

Xenakis was one of the first composers of notated music to employ split-tones, in his trombone work *Keren* (1986).[62] Tracing a chain of influence to Xenakis, trombonist and researcher James Lebens postulates that Xenakis was made aware of the technique by the soloist who premiered the work, Benny Sluchin, who had in turn learned it from his teacher, trombonist and composer Vinko Globokar (b. 1934).[63]

Press, 1979), 9.

60 Harold Lloyd Leno, *Lip Vibration Characteristics of Selected Trombone Performers*. Thesis (D. Mus. Arts) (University of Arizona, 1977).

61 Dave Wilken. "Lip Vibration of Trombone Embouchures, Leno, Part 3 of 3." YouTube. http://youtu.be/gmBDG_wAeS4?t=3m31s (retrieved October 25, 2013).

62 Iannis Xenakis, *Keren: pour trombone solo*. (Paris: Editions Salabert, 1989).

63 James C. Lebens, *An analysis of KEREN for solo trombone by Iannis Xenakis: randomly generated music within a symmetrical framework and performance considerations.* Thesis (D. Mus. Arts)

Split-tones on the trumpet are less well researched and less prevalent in the notated trumpet literature. Extended technique manuals by Paul Smoker (b. 1941)[64], Attilio Tribuzi[65], William Denton[66] and Amy Cherry[67], did not reveal any mention of the existence of split-tone multiphonics on the trumpet. They did mention singing while simultaneously playing, which produces similar, but less aggressively distorted sounds. Italian Gabriele Cassone (b. 1960) mentions the technique, but without providing an example of the technique in trumpet literature.[68] Cassone, in a similar way to Dempster, recommends learning the technique by bending a note downward until it splits onto the next harmonic, adding that "the lips must be kept very tightly closed and the lower jaw should be projected."[69] He also reveals some of the prejudice against the technique on the trumpet, mentioning that this is "the sound often played by accident by beginning brass players," the sound colloquially known as "fracking" – accidentally buzzing at a speed between two partials, which normally results in a noisy explosion of sound, followed by snapping onto the nearest partial.[70]

In my brief survey of notated trumpet music, I was only able to find a handful of pieces that use the technique, notably Liza Lim's (b. 1966) *Ehwaz* (2010)[71] and Eduardo

(University of Washington, 1993), 9-13.

64 Paul A. Smoker, *A comprehensive performance project in trumpet literature with a survey of some recently developed trumpet techniques and effects appearing in contemporary music*. Thesis (D.M.A.) (University of Iowa, 1974).

65 Attilio N. Tribuzi, *Extended trumpet performance techniques.* Thesis (M.A. in Music) (Calif. State University, Hayward, 1992).

66 William L Denton, *Extended trumpet techniques: a method for their exploration and mastery*. Thesis (D.M.A.) (University of South Carolina, 2006).

67 Amy K Cherry. *Extended techniques in trumpet perfomance and pedagogy.* Thesis (D.M.A) (Cincinnati, Ohio: University of Cincinnati, 2009). http://rave.ohiolink.edu/etdc/view.cgi?acc_num=ucin1242326372.

68 Gabriele Cassone, *The Trumpet Book* (Varese, Italy: Zecchini, 2009), 162.

69 Ibid., 162.

70 Ibid., 162.

71 Liza Lim, *Ehwaz (Journeying), für Trompete und Schlagzeug* (München: Ricordi, 2010).

Moguillansky's (b. 1970) brutally difficult *Limites* (2006-2008),[72] which requires the player to buzz on two trumpets, both with multiphonics, simultaneously. These works would not be possible without their virtuoso premiere players, Tristram Williams (b. 1978) in the case of *Ehwaz* and Valentín Garvie (b. 1973) in the case of *Limites*.

It is worth mentioning that split-tones have existed outside of the realm of notated music, in improvisations and non-notated music by jazz and experimental musicians. Trumpeter and composer Wadada Leo Smith (b. 1941) mentions that in jazz the technique originates from Booker Little (1938 – 1961) and Miles Davis (1926 – 1991). Leo Smith also notes that split-tones also occur accidentally due to fatigue:

> Multiphonics is easy [sic], it's when your lip gets tired and the little inner part gets relaxed a little bit and it buzzes or vibrates a little bit different. … While Booker Little was talking about being able to do that, he never quite affected it... The guys that made it most available, the three guys on the Plugged Nickel[73] date [1965] that Miles Davis did. He used multiphonics on there.[74]

Peter Evans (b. 1981) has explored split-tones as a compositional resource extensively and in a truly idiomatic fashion in the non-notated piece *The Chamber*, from his album *Nature/Culture*.[75] I was able to work with Evans during a UC San Diego residency of the International Contemporary Ensemble, which served to confirm that my experiments on my own instrument were indeed fairly universally applicable to other instruments as well as players.

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72 Eduardo Moguillansky, *Limites, for trumpet and small ensemble* (Self-published online: 2006-2008). http://www.moguillansky.info/limites.html (May 22, 2015).

73 Miles Davis, Wayne Shorter, Herbie Hancock, Ron Carter, and Tony Williams, *The complete Live at the Plugged Nickel 1965* (New York: Columbia Legacy, 1995).

74 Wadada Leo Smith, in conversation with Frank J. Oteri, "Wadada Leo Smith: Decoding Ankhrasmation," *New Music Box*, May 1, 2012. http://www.newmusicbox.org/articles/wadada-leo-smith-decoding-ankhrasmation/ (June 6, 2013).

75 Peter Evan, *Nature / Culture*, (London: Psi Records, 2009).

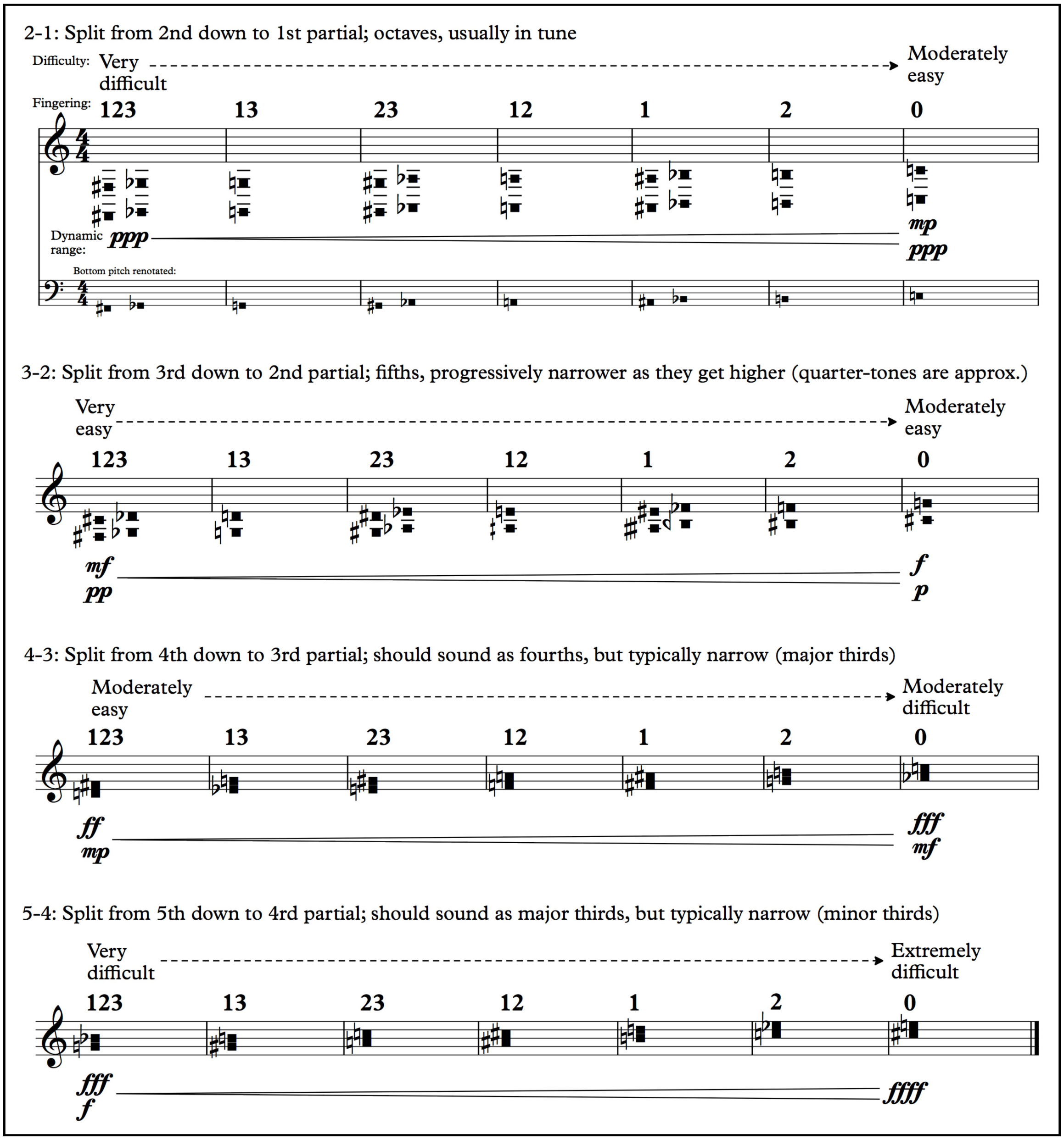

Figure 37. Written-pitch split-tones on C and B♭ trumpets. Square note heads are used to indicate the harsh beating sound associated with these multiphonics, in a similar fashion to Bartolozzi's notation for multiphonics with beating sounds in woodwinds.

There seemed to be some consistency in the tuning of the different partials within the split-tones, their difficulty, and the dynamics required to play them, as a function of their range. The most practical split-tones, at written pitch, sounding a major second lower on B♭ trumpets, are shown in figure 37. 3-2 split-tones are the easiest to learn, and the narrowing of the interval can be mitigated with practice; the same is true for the 4-3 split-tones, but to a lesser extent. The easier split-tones require rather reserved dynamic levels as well, making projection difficult in ensemble settings.

This research enabled me to write a progression of split-tone derived harmonies in the opening measures of the second movement of *Ouroboros*, from measure 33 to 47. The trumpet part is reproduced in figure 38. In addition to split-tone multiphonics, the trumpet player is asked to sing and play during the first two multiphonics, introducing further beating the sound. Half-valve glissandi are used as well, which sound particularly interesting in the way that the gritty sound of the split-tones is filtered by the partially-closed valves. This progression of multiphonics was used to generate a tone-row that was in turn used as a substitute for the circle-of-fifths pitch space active in *Apocryphal Chrysopoeia* during this movement.

The woodwind instruments (not shown in figure 38) in this section execute sing-and-play multiphonics, which are generally less strident than woodwind split-fingering multiphonics, allowing the reserved character of the trumpet multiphonics to speak through the texture. The string instruments execute a variety of narrow glissandi in conjunction with an open string, a very similar sound to sing-and-play multiphonics. Amplification was also used to aid in the balance of the ensemble. The electronic sounds provided by *Aprocryphal Chrysopoeia* during this section use the *skitter* effect, which creates beating patterns similar to those in the wind multiphonics and wandering string dyads.

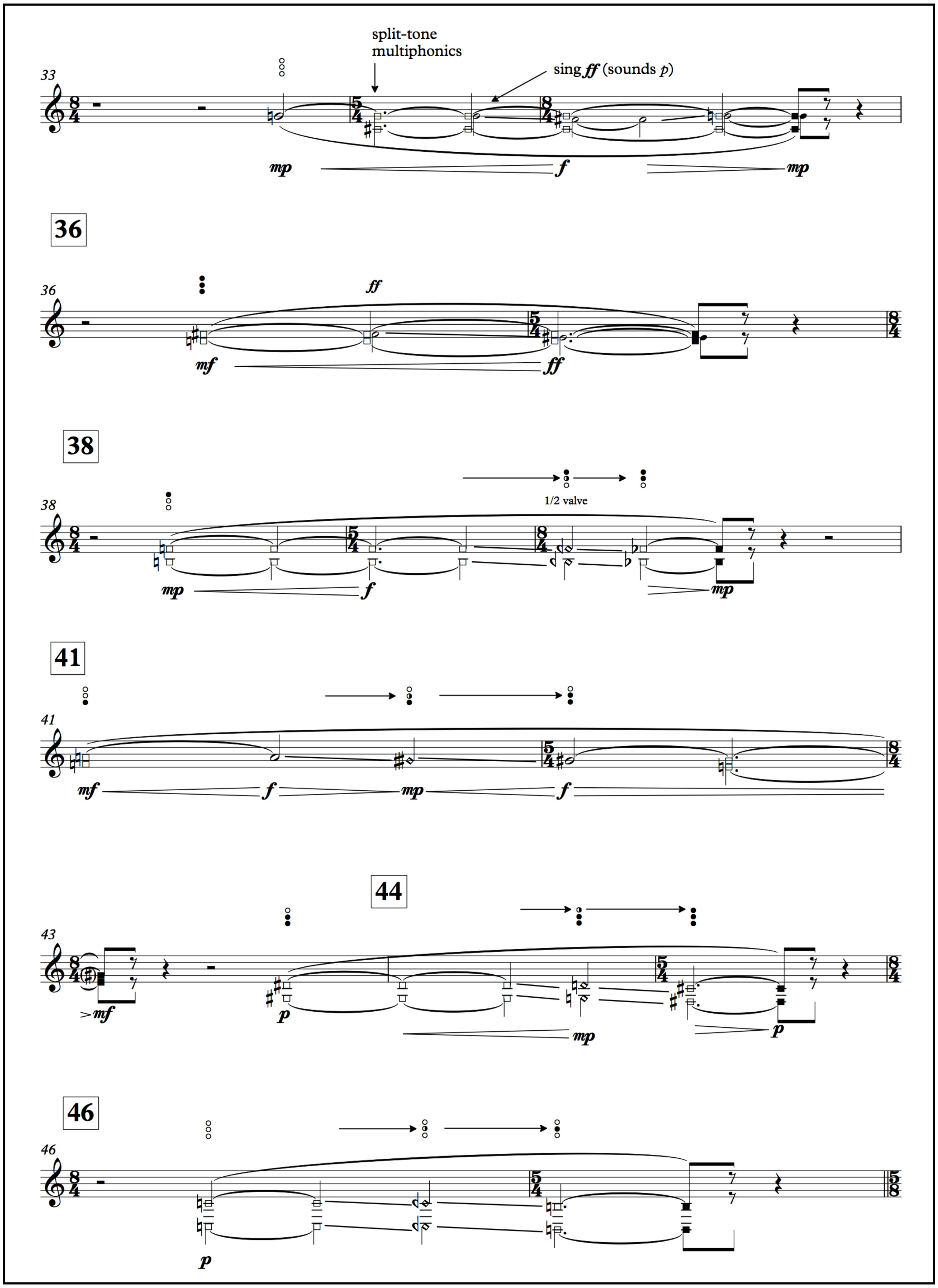

Figure 38. Split-tone texture in the trumpet, *Ouroboros*, m. 33 – 47.

1.4 The Construction of a Text

The text collage that serves to inform the structure of *Ouroboros* was assembled from several sources. The "spine" of the text is taken from E.T.A. Hoffmann's (1776 – 1822) *Der Sandmann* (*The Sandman*)(1816), in the classic 1844 English translation by John Oxenford (1812 – 1877)[76]. Hoffmann's tale was initially attractive to me because of the uncanny automaton Olympia. However, the story incorporates many more concepts that I came to adopt as parts of the theme for *Ouroboros*. One of these concepts is seduction through illusion – Olympia, though marginally lifelike to the background characters in the story, is exponentially more vivacious to the main character Nathanael because he first views her through a (probably magical) pocket-telescope given to him by the optician Coppola. Coppola himself is an uncanny double of the alchemist Coppelius, experienced in Nathanael's youth as the Sandman. The pocket-telescope has become in the dissertation an allegory for my own seduction by audio-visual simulations and automata.

Literary criticism also fueled my explorations of Hoffmann's tale. In particular, I found the image of the "circle of fire" (*Feuerkreis*) to be resonant with my own experiences of automata, fictional or simulated:

> ...[*the Sandman*] reaches a climax … And it is accompanied by a kind of pyrotechnic display – a performance of compulsive repetition: … "Fire circle turn thyself" … This is the circle of fire that turns around and through the text, the electrical short circuit that accompanies the technological fantasy. Hoffmann was participating in the ambivalent fascination with electromagnetic forces that was characteristic of early nineteenth-century literary culture and subjecting it to a destructive form of feedback. The current circulates here around the body of the automaton

76 E.T.A. Hoffmann, "The Sandman," in *Tales from the German, comprising specimens from the most celebrated authors,* trans. John Oxenford and C. A. Feiling (1844)(Republished, Project Gutenberg, 2010). http://www.gutenberg.org/etext/32046 (May 20, 2015).

> at the core of that fantasy, representing at once its repetitive compulsive power and its in-built self-destructive liability.[77]

Though our understanding and control of natural forces such as electricity and magnetism have increased since Hoffmann's time, the simultaneous existence of technological fantasy and ambivalence continue to exist in our contemporary culture. This ambivalence is one of the continued forces at work in Medosch's contemporary *romanticism noir,* driving its information age landscape painters to critique the assumed progress of various technologies.

Though the Hoffmann story informs the structure of the work, very little of the text manages to assert itself in the final supertitles. This is primarily because Hoffmann's imagery is so lurid that I thought it could be distracting when placed against more-or-less abstract music and moving images. Instead, I have used text from Heinrich von Kleist's (1777 – 1811) "On the Marionette Theater," (1810) in the translation by Idris Parry (1916 – 2008),[78] to tell the story of the Hoffmann, replacing Hoffmann's words with Kleist's when their meaning aligns (or misaligns) in interesting ways, creating a palimpsest.

Kleist's story, in which a narrator converses with a dancer who is fascinated with the marionette theater, is quite sober in tone when compared with the Hoffmann. The dancer seems convinced that he could potentially build a perfect puppet, capable of dance more graceful than any human conscious of her or his own actions. This almost positivist[79] view of what technology might accomplish is at odds with the paranoid,

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77 Andrew Webber, "About face : E. T. A. Hoffmann, Weimar film, and the technological afterlife of gothic physiognomy," in *Popular revenants: the German gothic and its international reception, 1800-2000*, eds. Andrew Cusak and Barry Murnane (Rochester, NY: Camden House, 2012), 167.

78 Heinrich von Kleist, "On the Marionette Theater," trans. Idris Parry, in *Hand to mouth and other essays*. (Manchester: Carcanet New Press, 1981).

79 It may be unwise to invoke such a complex philosophical discourse as positivism. I simply mean here that Kleist's character seems to believe strongly in his ability to observe reality, abstract relationships

ambivalent view of technology found in the Hoffmann. Contemplating the Hoffmann while reading the Kleist saturates the latter's words with irony and sarcasm, though a kind of perverse hope remains at the core.

In addition to the core texts of the Hoffmann and Kleist, the narrative structure of *Ouroboros* is infused with fragments from two other sources: Ovid's (43 BC – 18 AD) "Story of Pygmalion" from *Metamorphoses*, in translation by Samuel Garth (1661 – 1719),[80] and Jules Barbier's (1825 – 1901) libretto to Jacque Offenbach's (1819 – 1880) opera *Tales of Hoffmann* (1876 – 1880), translated by Charles Henry Meltzer (1853 – 1936).[81] From the latter I briefly quote sections of the Doll's Aria.

Between sections of the narrative text collage, critical texts on the relationship of technology and abstraction to humanity in general and art in particular form *attacca* interludes. Here the teeth of *Ouroboros* sink into its tail – the texts directly address exactly what *Apocryphal Chrysopoeia* is intended to do: to transform the leaden material of numeric abstraction into a golden feast for the visual and auditory senses.

All of these texts inform the choices of visual and auditory phenomena that accompany them, using the chamber ensemble and audio-visual virtual instrument. Sometimes the audio-visual events directly correlate with the text, and at other times the audio-visual events have oblique or contrary relationships with the text.

A list of all correspondences between the text and audio-visual elements would be overwhelmingly dry and didactic, but a few moments are worth mentioning. In the first

from that reality, and then act on those abstractions to create something with a specific goal. He believes that he understands the laws of gracefulness, and can act on his understanding of those laws.

80 Ovid, *Metamorphoses: in fifteen books*, trans. Samuel Garth (New York: Heritage Press, 1961).

81 Jacques Offenbach, Jules Barbier, and Michel Carré, *The Tales of Hoffmann*, trans. Charles Henry Meltzer (New York: G. Schirmer, 1940).

movement, the text is taken from the introductory scene in the Hoffmann, where the protagonist Nathanael encounters his father, working with the Sandman, on some kind of secret alchemical project. Nathanael vividly remembers being disassembled, limb by limb, by the Sandman, as if Nathanael were an automaton himself (the veracity of his claims are doubted by his lover Clara).[82] Parts of the Kleist, dealing with the lifeless swinging of perfect marionette limbs, are superimposed over the Hoffmann, and used in the supertitles. The cracking sounds accompanying Nathanael's dismemberment are echoed in the music, through the application of the *crush* effect in the audio-visual instrument, and through the popping sounds in the ensemble: muted piano, key clicks, slap tongue, ram tongue, snap-*pizzicato* and strings struck *col legno battuto*.

In the third movement, the Kleist is seemingly at odds with the Hoffmann. While the latter details Nathanael uncontrollably raging about, the former calmly meditates on humankind's expulsion from, and potential to return to, mythical paradise. Here, the music is driven by the cyclical diverging and converging tempo structures mentioned earlier – metaphoric circles of fire. Built on top of these cycles, the music oscillates between the calm of the Kleist and the fury of the Hoffmann, through the amplification or attenuation of the tempo structures by surface level rhythmic motives. The digital audio-visual elements provide a more continuous backdrop to the frenetic activity of the instruments, though they too are driven by several layers of cyclical activity.

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82 This foreshadows Nathanael's demise at the end of the story, when he loses control over his own actions, attacking Clara and plummeting to his death, seemingly by the will of the Sandman. One could interpret this loss of control as Hoffmann's own fear of the newly discovered, in his time, control of muscle tissue with electricity – the “circle of fire.”

1.4.1 Libretto with References

The following section includes the entire text collage used for the libretto of *Ouroboros*. The *attacca* interludes, formed by critical texts, are given explicit references to their sources, including page numbers, while the sources for the quasi-narrative primary text may be differentiated by their indentation: none for Hoffmann, one for Kleist, two for Ovid and three for Barbier. The page sources for these narratives texts are much more erratic, and thus are omitted, because it would be much too cluttered to include them. As in normal quotations, omitted material in the collage is demarcated by ellipses, while brackets show paraphrasing.

Section. I. a.: Unknown Material

In a way, individual scientists, scientific movements, tribes, nations function like artist or artisans trying to shape a world from a largely unknown material, Being. … Working on [this material, they] build a variety of manifest worlds that they often, but mistakenly, identify with Being itself.[83]

Section I. b.: Secret Alchemy

secret alchemical experiments
a fallacious desire after higher wisdom

a blue flame began to crackle upon the hearth
all sorts of strange utensils lay around
[With] red-hot tongs

[The] sculptor exercised ... skill...

[taking] glowing masses out of the thick smoke; which ... afterwards [were] hammered. ...

carv[ing] … a [form], as Nature could not with [its]

83 Paul Feyerabend, "Theoreticians, artists and artisans," *Leonardo / Leonardo, the International Society for the Arts, Sciences and Technology* 29 (1996), 27.

art compare

… a marionette [with the right] specifications …

... without any eyes ... with deep holes instead.

… Never ... guilty of affectation

... joints cracked

… the … limbs,

hands, and feet, [screwed off],
afterwards putting them back again, one after the other,

[would] be just what they should be,

… lifeless, pure pendulums, governed only the law of gravity.

... all around became black, a sudden cramp darted through bones and nerves

… [T]he human spirit can't be in error when it is non-existent.

Section I. c.: Figure Sculpture

… [W]e may look upon the long tradition of figure sculpture and the brief interlude of formalism as an extended psychic dress rehearsal … [T]he Greek obsession with 'living' sculpture will take on an undreamed reality.[84]

Section I. d.: Spectacles

[S]pectacles ... glisten and sparkle ...
A thousand eyes stared and quivered ...
and all those flaming eyes leapt in wilder and wilder confusion,
shooting [forth] their blood red light…

Pleased with [the] idol, [the sculptor] admires,
adores, … and desires.

Never ... had ... a glass ... [rendered] objects so clearly and sharply...
... wondrous beauty ... [yet] with ... eyes ... singularly still and dead.
Nevertheless,

84 Jack Burnham, *Beyond modern sculpture: the effects of science and technology on the sculpture of this century* (New York: Braziller, 1969), 376.

It caught the carver [in its] deceit

... looked more keenly through the glass,
... moist moonbeams rising ...
...flash[ing] with constantly increasing life.
Fire penetrate[s the] inmost soul ...

… clutch[ing] with burning arms,
[and] hands as cold as ice;

... [a] pulse began to beat
life's blood flow[s]...

… [flushed with blood] ...

[the dream breaks with] humming and scraping

Section II. a.: Synthetic Biology

Research on artificial life … does not perform experiments on living matter, but rather [involves experiments with simulations]. … [T]he phenomena being reproduced and studied are not life-phenomena, but [abstractions]. … A more accurate appellation … might be "synthetic biology.[85]

Section II. b.: Aria

She

[had] the advantage of being … weightless.

play[ing]the harpsichord with great dexterity,

[a puppet] not afflicted with the inertia of matter …

[while] sing[ing] a virtuoso piece.

The birds in the bushes,
in the heavens the orb of day
speaks *to the young girl of love, of love!*
Voila! The pretty song, Voila! The song of Olympia,

85 Edward A. Shanken, "Life as we know it and or life as it could be: epistemology and the ontology/ontogeny of artificial life". *Leonardo / Leonardo, the International Society for the Arts, Sciences and Technology* 31 (1998), 386-387.

Ha!

[propelled into the air]

a voice like the sound of a glass bell,
clear and piercing,

All that sings and resounds
Has its sighs in turn*,*
Moves its heart that trembles *with love.*
Voila. The little song, Voila, voila, The song of Olympia, Ha!

Section II. c.: Dance

The somewhat strange arch of her back
and the wasp-like thinness of her waist...

The marionette glances against the ground only lightly
Through this momentary check, renews the swing of limbs

In her step and deportment...
something measured and stiff.

The limbs are only pendulums, [and] follow mechanically of their own accord.

… When the centre of gravity is moved in a straight line, the limbs describe curves...

... the feet of the figure ...

.. shaken in a … haphazard way

... dangled in the most hideous manner

[they fall] into a kind of … dance.

… [rattling] with a wooden sound on every step.

Section II. d.: Catalytic Relays

…[A]rbitrary … transcodings, … uncritical transpositions of artificial life, … neglect qualitative, affective transformations [in] sonic culture. [But it] is never a closed system, [instead] a catalytic network of relays connecting one analog domain to another.[86]

Section II. e.: Perhaps

…[W]ere I to believe that I … had actually created life in a computer, I might think of … our relationship to the cosmos somewhat differently ... but that does not mean I am unchanged...[87]

Section III. a.: The Cherubim (or, *Feuerkreis*)

Paralyzed
Her waxen, deathly-pale countenance had no eyes,
but black holes instead - she was, indeed, a lifeless doll.
... the eyes stolen ... ... there you see the eyes!
... a pair of eyes lay upon the ground, staring ...

> we've eaten of the tree of knowledge...
> paradise is locked and bolted,
> cherubim stand behind us

madness seized ... in its burning claws,
clutched [the] soul, destroying ... every sense and thought.
A circle of fire! of fire! Spin round, circle!

> We have to ... journey round the world,
> perhaps it is open at the back

Crying out ... words ... merged into one hideous roar like that of a brute
Pale as death ... streams of fire flashed and glared from ... rolling eyes,

> as thought grows dimmer...
> grace emerges more brilliantly...

Roar[ing] frightfully, like a hunted beast.
Spring[ing] high into the air

> But … grace itself returns when [awareness] has ... gone through an infinity.

punctuating words with horrible laughter
shrieked out in a piercing tone
'Spin round, wooden doll! - spin round!'

86 Steve Goodman, “Sonic Algorithm,” in *Software Studies: A Lexicon,* ed. Matthew Fuller (Cambridge, MA: MIT, 2008), 229.
87 Shanken, "Life as we know it,” 388.

> Grace appears most purely in that ... form which either has no consciousness,

... raging about the gallery,
leaping high in the air and crying,
'Circle of fire spin round! spin round!'

> or an infinite consciousness.

Suddenly ... still as if petrified.
' pretty eyes - pretty eyes!'
... over the railing.
... stone pavement ... head shattered...

Section III. b.: Unintended Consequences

[P]rograms are buggy ... formal logics are inherently incomplete ... machines break down … projects are abandoned and systems hacked. … [H]umans are literally infected by abstractions.

This is no bad thing, because like the virus which produced variegated tulips of a rare beauty, infection can be creative too.[88]

1.4.2 Libretto Formatted for Program Notes

For the purposes of concert program notes, the libretto should be printed exactly as follows. The grey text shows material that is treated as a palimpsest – it is not present in the supertitles, but informs the structure and affect of the music and visuals. The fonts show sources: Avenir, a sans serif font, should be used for the *attacca* critical interludes, while Palatino, a serif font, should be used for the narrative primary texts. Indentation provides clues to the origins of the text, but this should not be made overly explicit.

88 Andrew Goffey, "Algorithm," in *Software Studies: A Lexicon,* ed. Matthew Fuller (Cambridge, MA: MIT, 2008), 19.

Ouroboros **– Text**

I.

Unknown Material

In a way, individual scientists, scientific movements, tribes, nations function like artist or artisans trying to shape a world from a largely unknown material, Being. Working on this material, they build a variety of manifest worlds that they often, but mistakenly, identify with Being itself.

– Paul Feyerabend, "Theoreticians, Artists and Artisans."

Secret Alchemy

secret alchemical experiments
a fallacious desire after higher wisdom

a blue flame began to crackle upon the hearth
all sorts of strange utensils lay around
With red-hot tongs

the sculptor exercised skill

taking glowing masses out of the thick smoke, which afterwards were hammered

carving a form, as Nature could not with its art compare

a marionette with the right specifications

without any eyes, but with deep holes instead

Never guilty of affectation

joints cracked

the limbs,

hands, and feet, screwed off,
afterwards putting them back again, one after the other,

would be just what they should be,
lifeless, pure pendulums, governed only the law of gravity.

all around became black, a sudden cramp darted through bones and nerves

The human spirit can't be in error when it is non-existent.

Figure Sculpture

We may look upon the long tradition of figure sculpture and the brief interlude of formalism as an extended psychic dress rehearsal. The Greek obsession with 'living' sculpture will take on an undreamed reality.

– Jack Burnham, *Beyond Modern Sculpture*

Spectacles

Spectacles glisten and sparkle
A thousand eyes stared and quivered
and all those flaming eyes leapt in wilder and wilder confusion,
shooting forth their blood red light

Pleased with the idol, the sculptor admires,
adores, and desires.

Never had a glass rendered objects so clearly and sharply
wondrous beauty yet with eyes singularly still and dead
Nevertheless,

It caught the carver in its deceit

looked more keenly through the glass,
moist moonbeams rising
flashing with constantly increasing life
Fire penetrates the inmost soul

clutching with burning arms,
and hands as cold as ice

a pulse began to beat
life's blood flows

flushed with blood

the dream breaks with humming and scraping

II.

Synthetic Biology

Research on artificial life does not perform experiments on living matter, but rather involves experiments with simulations. The phenomena being reproduced and studied are not life-phenomena, but abstractions. A more accurate appellation might be "synthetic biology."

– Edward Shanken, *Life as we know it and/or life as it could be*

Aria

She

had the advantage of being weightless.

playing the harpsichord with great dexterity,

a puppet not afflicted with the inertia of matter

while singing a virtuoso piece

The birds in the bushes
In the heavens the orb of day,
Speaks *to the young girl of love, of love!*
Voila! The pretty song, Voila! The song of Olympia, Ha!

propelled into the air

a voice like the sound of a glass bell,
clear and piercing,

All that sings and resounds
Has its sighs in turn,
Moves its heart that trembles *with love*
Voila. The little song, Voila, voila, The song of Olympia, Ha!

Dance

The somewhat strange arch of her back
and the wasp-like thinness of her waist

The marionette glances against the ground only lightly
Through this momentary check, renews the swing of limbs

In her step and deportment
something measured and stiff

The limbs are only pendulums, and follow mechanically of their own accord.

When the centre of gravity is moved in a straight line, the limbs describe curves

the feet of the figure

shaken in a haphazard way

dangled in the most hideous manner

they fall into a kind of dance.

rattling with a wooden sound on every step

Catalytic Relays

Arbitrary transcodings, uncritical transpositions of artificial life, neglect the qualitative, affective transformations in sonic culture. But they are never closed systems, instead catalytic networks of relays connecting analog domains to one another.

– Steve Goodman, *Software Studies*

Perhaps

Were I to believe that I had actually created life in a computer, I might think of our relationship to the cosmos somewhat differently. But that does not mean I am unchanged.

– Edward Shanken, *Life as we know it and/or life as it could be*

III.

The Cherubim

Paralyzed
Her waxen, deathly-pale countenance had no eyes,
but black holes instead - she was, indeed, a lifeless doll
the eyes stolen ... there you see the eyes!
a pair of eyes lay upon the ground, staring

we've eaten of the tree of knowledge
paradise is locked and bolted,
cherubim stand behind us

madness seized in its burning claws,
clutched the soul, destroying every sense and thought
A circle of fire! of fire! Spin round, circle!

We have to journey round the world,
perhaps it is open at the back

Crying out words merged into one hideous roar like that of a brute
Pale as death, streams of fire flashed and glared from rolling eyes

as thought grows dimmer
grace emerges more brilliantly

Roaring frightfully, like a hunted beast
Springing high into the air

But grace itself returns when awareness has gone through an infinity.

punctuating words with horrible laughter
shrieked out in a piercing tone
Spin round, wooden doll! - spin round!

Grace appears most purely in that form which either has no consciousness,

raging about the gallery,
leaping high in the air and crying,
Circle of fire spin round! spin round!

or an infinite consciousness.

Suddenly still as if petrified.
pretty eyes - pretty eyes!
over the railing
stone pavement
head shattered

Unintended Consequences

Programs are buggy, formal logics are inherently incomplete, machines break down, projects are abandoned and systems hacked. Humans are literally infected by abstractions.

This is no bad thing, because like the virus which produced variegated tulips of a rare beauty, infection can be creative too.

– Andrew Goffey, Software Studies

Unless otherwise noted, the text is a collage of several sources:

E.T.A Hoffmann's *The Sandman*, translated by John Oxenford

Heinrich von Kleist's "On the Marionette Theater," translated by Idris Parry

Jacques Offenbach and Jules Barbier's *Tales of Hoffmann*, translated by Charles Henry Meltzer

Ovid's *Metamorphoses*, translated by Samuel Garth

1.5 Conclusion

A variety of interdisciplinary resources were analyzed, experimented with and brought into relationships with each other during the composition of *Ouroboros,* a work for ensemble and digital audio-visual media, and the programming of *Apocryphal Chrysopoeia*, a software instrument used in conjunction with *Ouroboros*. *Ouroboros* is temporally and conceptually structured around a text collage: a palimpsest of Hoffmann's *The Sandman* with Kleist's "On the Marionette Theatre." These fictional texts deal with both the peril and promise of automata. Excerpts of non-fiction critical texts on the relationship of algorithms to music and art are embedded in the collage as well, and the results are projected during the performance as supertitles. The ensemble music and digital audio-visual media provide a counterpoint with the texts, sometimes directly paralleling qualities within them, while at other times moving indifferently or in opposition to the texts.

The music and audio-visual media in *Ouroboros* bear traces of algorithmic processes, the real and virtual physics of instruments, and manual interventions with these forces due to my sensibilities. Musically, the modulation of harmonic fields is created through changing spatial relationships of audio-visual modules within the virtual instrument *Apocryphal Chrysopoeia*. The initial inspiration for the spatial arrangement of these modules came from pitch space theories found in the literature of music psychology, although playful manipulation and interpretation of these spaces has resulted in aberrant behavior only acceptable within a creative context. Visually, I sought to find synchresis between the auditory and visual behaviors that was potent, but not cartoonishly mimetic, drawing upon influences in the visual music tradition.

The harmonic fields generated by *Apocryphal Chrysopoeia* bound the pitch material in both the electronic and acoustic instruments. A cellular automaton articulates this material in the electronics, creating variegated but principled patterns in both sound and light. The instrumentalists execute a variety of textures, often structured through imitative counterpoint in multiple tempi, that articulate the same harmonic fields. Sometimes instrumental techniques, such as split-tone multiphonics in the trumpet, suggest specific pitch and timbral material based on the physical restrictions of the instrument, requiring corresponding alterations in the control of the virtual instrument.

The resulting welter of music, visual media and text is consciously aimed at eliciting the experience of the sublime in audience members. It partakes in both the mathematic and dynamic sublime, rendering audio-visual scenes with uncountable numbers of facets and tones, turbulently shifting and changing density. It is akin to theorist Armin Medosch's *landscape paintings of the information age*, in its reliance on data sonification and visualization. Or it is a gothic audio-visual novel in the proposed *romantic noir* tradition, spinning out several simultaneous and perhaps fatally incommensurable tales of the relationships of humankind, technology, and art.

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2

Audio-visual score to *Ouroboros*

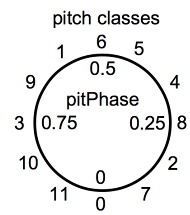
Initial values for each movement are provide in colored boxes according to their fader/potentiometer color in the performance patch.

Audio-visual score – explanation

excDens: 50	rotDur: 0	rotRad: 100	distFade: 100	timeJitter: 1	skitter: 1	scramble: 1	attack: 1	grains: .4
audioDens: 100	videoDens: 100	camHite: 25	orbScl: 4	wander: 1	spectre: 0	crush: 127	wet: 85	master: 127

Cells activate with
2 or 3 active neighbors
Cells stay active with
3 or 4 active neighbors

Information about the cellular automaton is provided in a box.

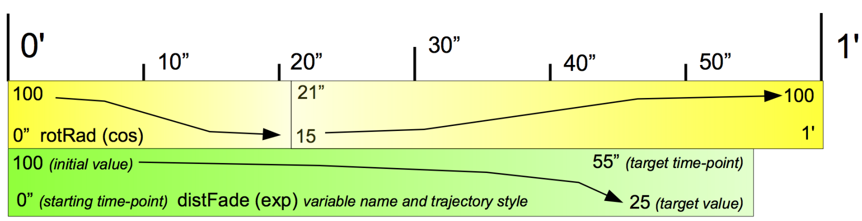


Assignment of pitch-classes to the base structure of audio-visual modules is provided in a ring. Pitch phase values are on the inside, pitch-classes on the outside.

Other variables:
tempo: 3000 ms
lookAt: 4
decay: 1

Other variables may be listed as well.

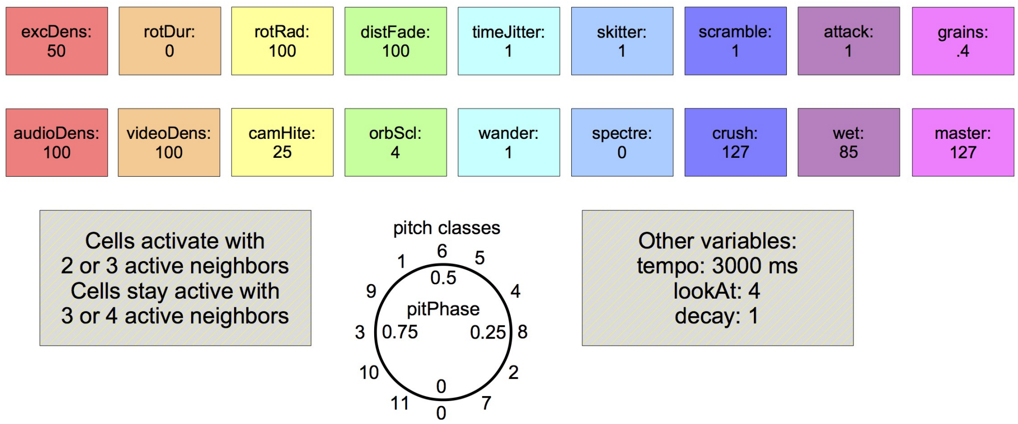
A temporal guide is provided.



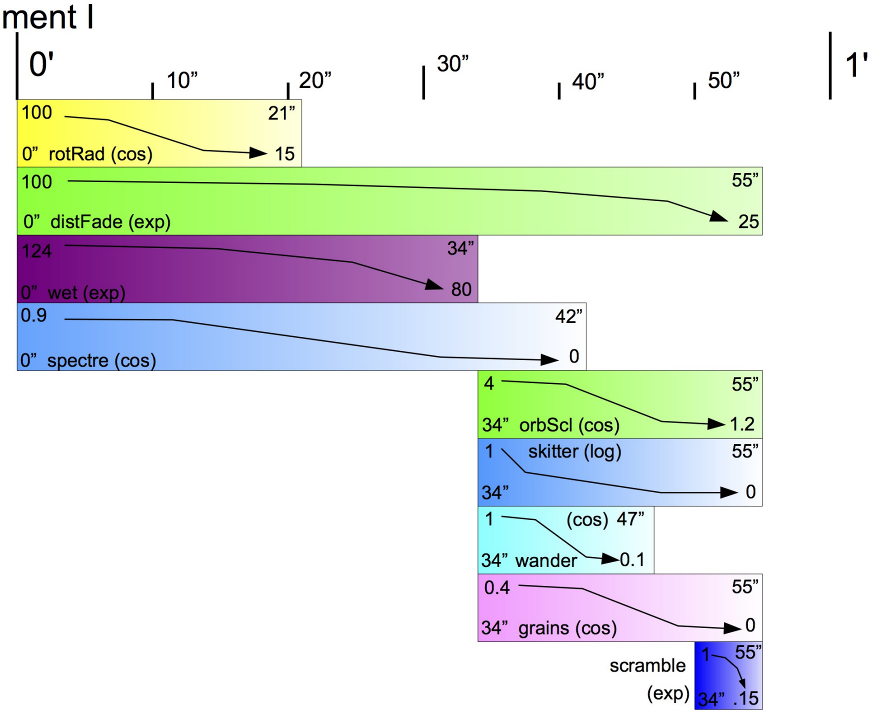
Variables changing over time at any moment are depicted with boxes. Color gradients assist in showing the changing depth of effects. A variety of information is shown within the boxes (see italics above).

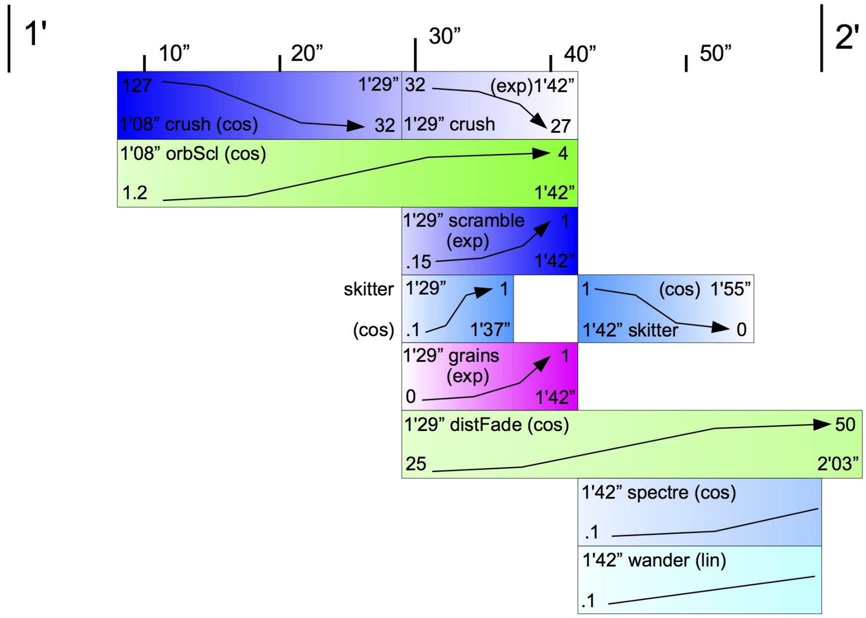
Trajectory styles:
cos = half cosine   exp = exponential
log = logarithmic   lin = linear

Movement I – Initial Values

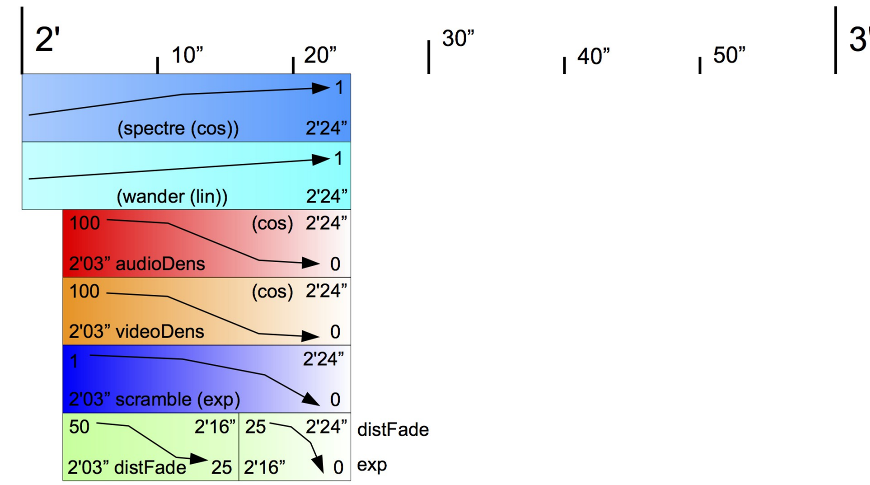


Movement I

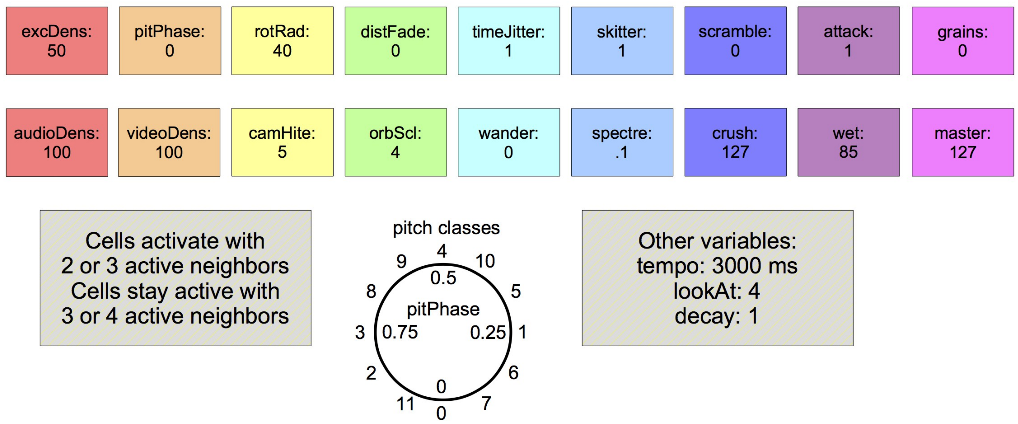




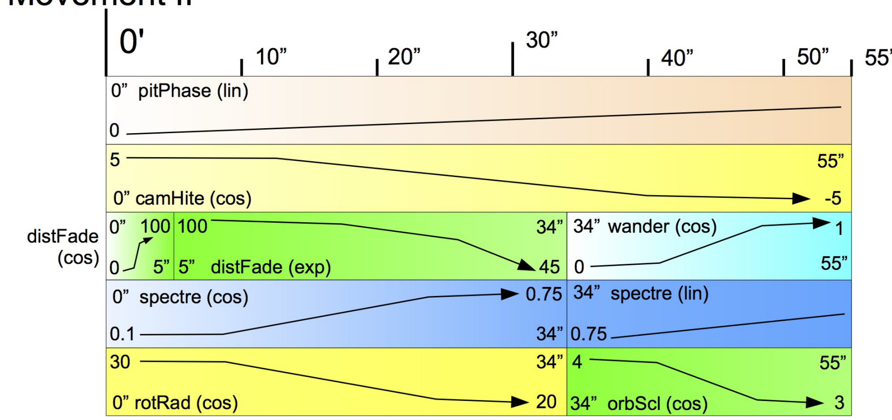
1'
10”
20”
30”
40”
50”
2'
127
1'29”
1'08” crush (cos)
32
32
(exp)1'42”
1'29” crush
27
1'08” orbScl (cos)
4
1.2
1'42”
1'29” scramble
(exp)
1
.15
1'42”
skitter
(cos)
1'29”
1
.1
1'37”
1
(cos) 1'55”
1'42” skitter
0
1'29” grains
(exp)
1
0
1'42”
1'29” distFade (cos)
50
25
2'03”
1'42” spectre (cos)
.1
1'42” wander (lin)
.1

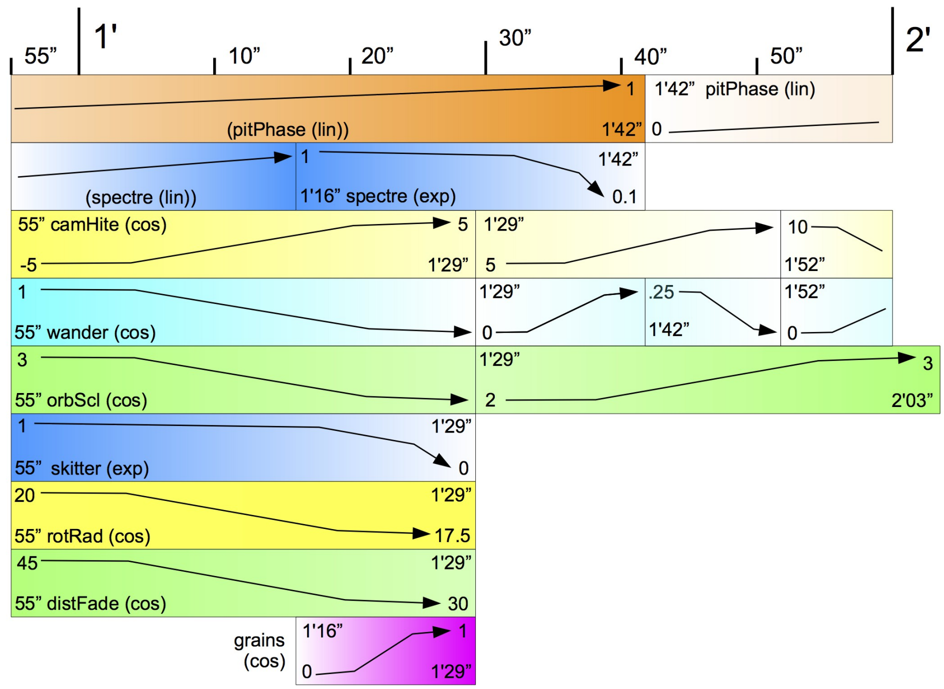

2'
10”
20”
30”
40”
50”
3'
1
(spectre (cos))
2'24”
1
(wander (lin))
2'24”
100
(cos)
2'24”
2'03” audioDens
0
100
(cos)
2'24”
2'03” videoDens
0
1
2'24”
2'03” scramble (exp)
0
50
2'16”
25
2'24”
distFade
2'03” distFade
25
2'16”
0
exp

Movement II – Initial Values

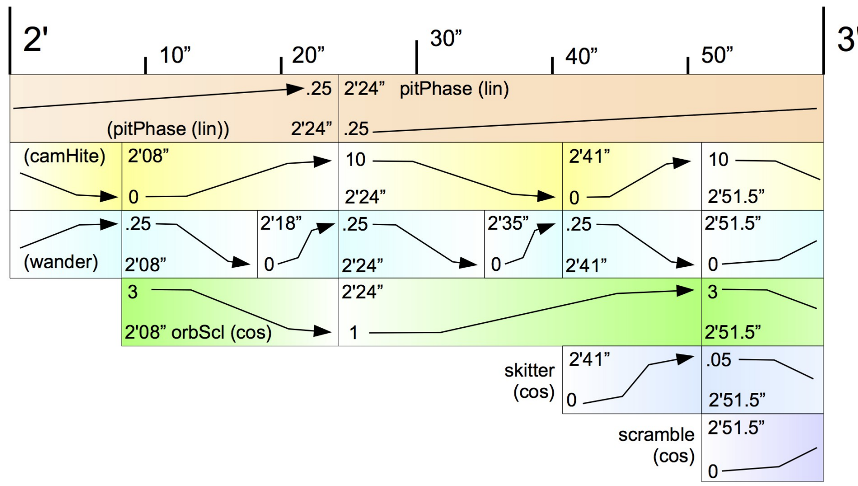


Movement II

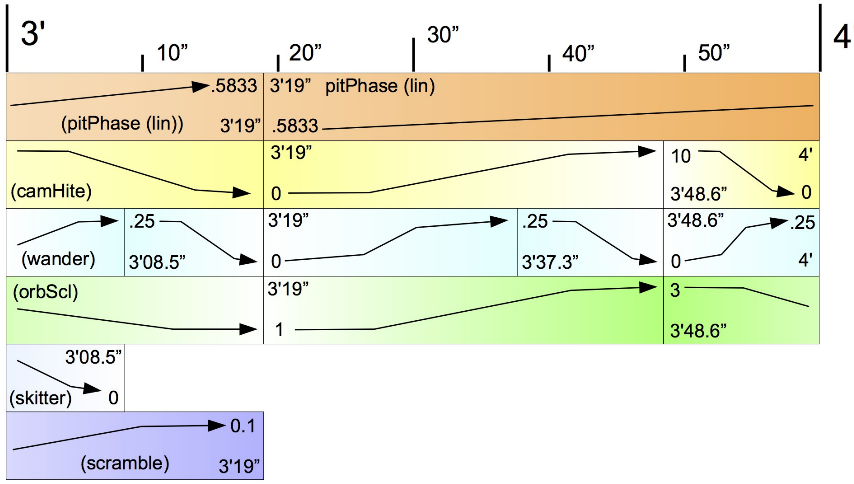


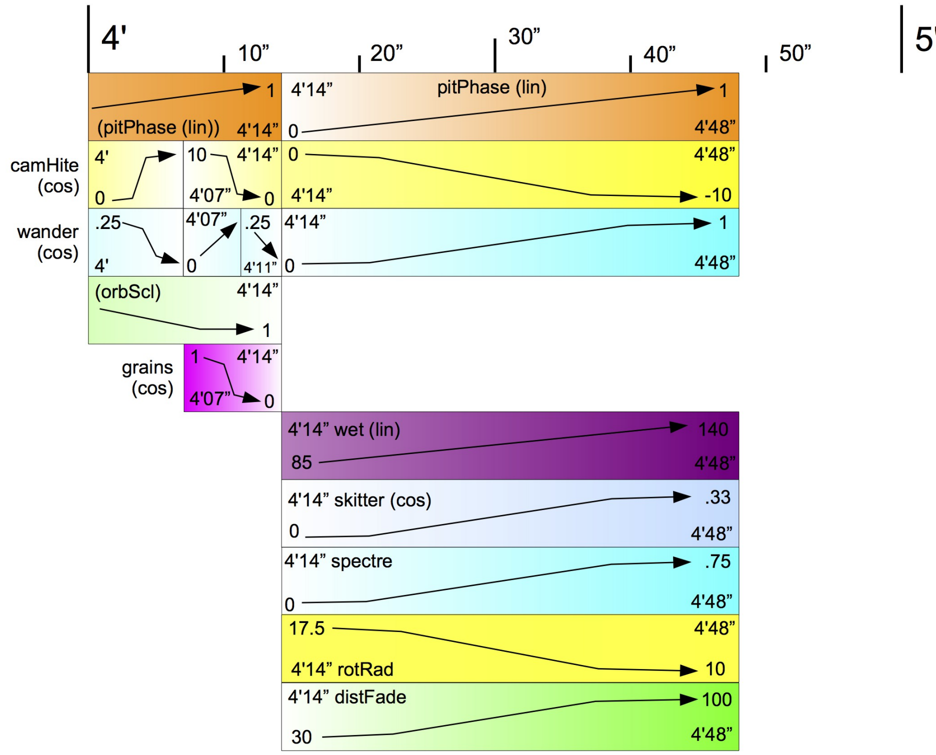


55”
1'
10”
20”
30”
40”
50”
2'
1
1'42” pitPhase (lin)
(pitPhase (lin))
1'42”
0
1
1'42”
(spectre (lin))
1'16” spectre (exp)
0.1
55” camHite (cos)
5
1'29”
10
-5
1'29”
5
1'52”
1
1'29”
.25
1'52”
55” wander (cos)
0
1'42”
0
3
1'29”
3
55” orbScl (cos)
2
2'03”
1
1'29”
55” skitter (exp)
0
20
1'29”
55” rotRad (cos)
17.5
45
1'29”
55” distFade (cos)
30
grains
(cos)
1'16”
1
0
1'29”



2'
10"
20"
30"
40"
50"
3'
.25
2'24" pitPhase (lin)
(pitPhase (lin))
2'24"
.25
(camHite)
2'08"
0
10
2'24"
2'41"
0
10
2'51.5"
.25
2'18"
.25
2'35"
.25
2'51.5"
(wander)
2'08"
0
2'24"
0
2'41"
0
3
2'24"
3
2'08" orbScl (cos)
1
2'51.5"
skitter
(cos)
2'41"
0
.05
2'51.5"
scramble
(cos)
2'51.5"
0

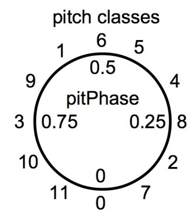

3'
10"
20"
30"
40"
50"
4'
.5833
(pitPhase (lin))
3'19"
3'19" pitPhase (lin)
.5833
(camHite)
3'19"
0
10
4'
3'48.6"
0
(wander)
.25
3'08.5"
3'19"
0
.25
3'37.3"
3'48.6"
0
.25
4'
(orbScl)
3'19"
1
3
3'48.6"
3'08.5"
(skitter)
0
0.1
(scramble)
3'19"


4'
10”
20”
30”
40”
50”
5'
(pitPhase (lin))
4'14”
pitPhase (lin)
4'48”
camHite (cos)
4'07”
-10
wander (cos)
.25
4'11”
(orbScl)
grains (cos)
4'14” wet (lin)
85
140
4'14” skitter (cos)
.33
4'14” spectre
.75
17.5
4'14” rotRad
10
4'14” distFade
30
100

Movement III – Initial Values

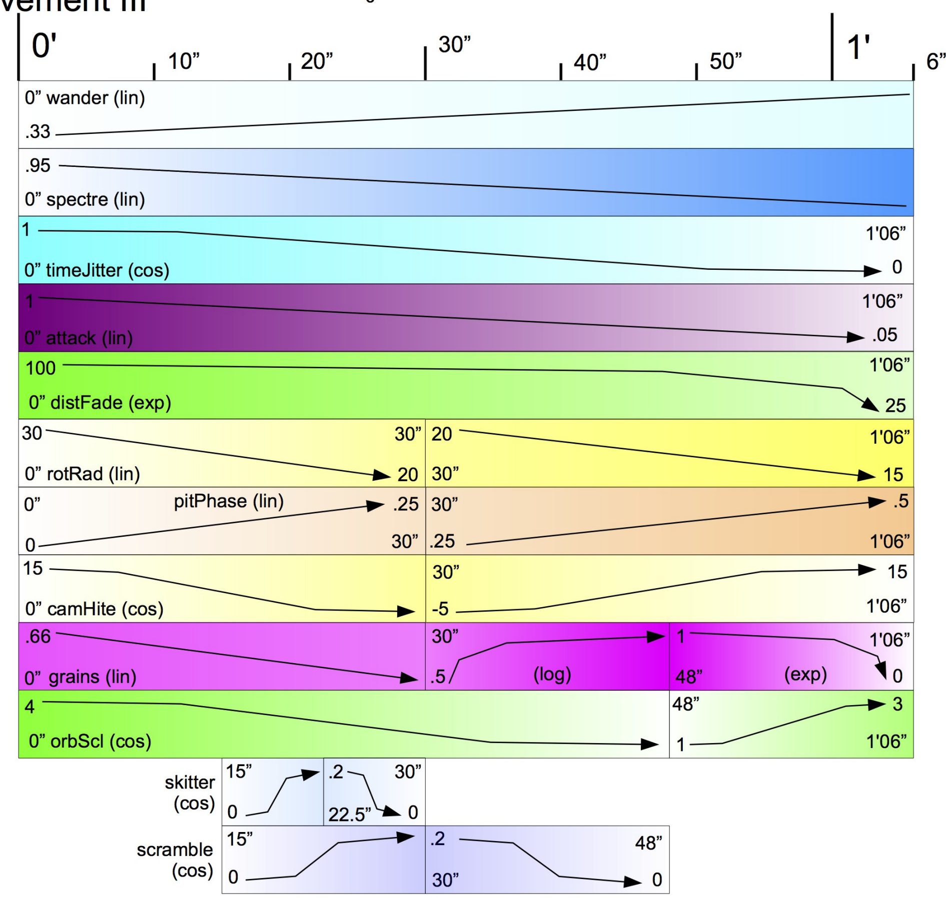
excDens: 50	pitPhase: 0	rotRad: 30	distFade: 100	timeJitter: 1	skitter: 0	scramble: 0	attack: 1	grains: .66
audioDens: 100	videoDens: 100	camHite: 10	orbScl: 4	wander: 0	spectre: .95	crush: 127	wet: 85	master: 127

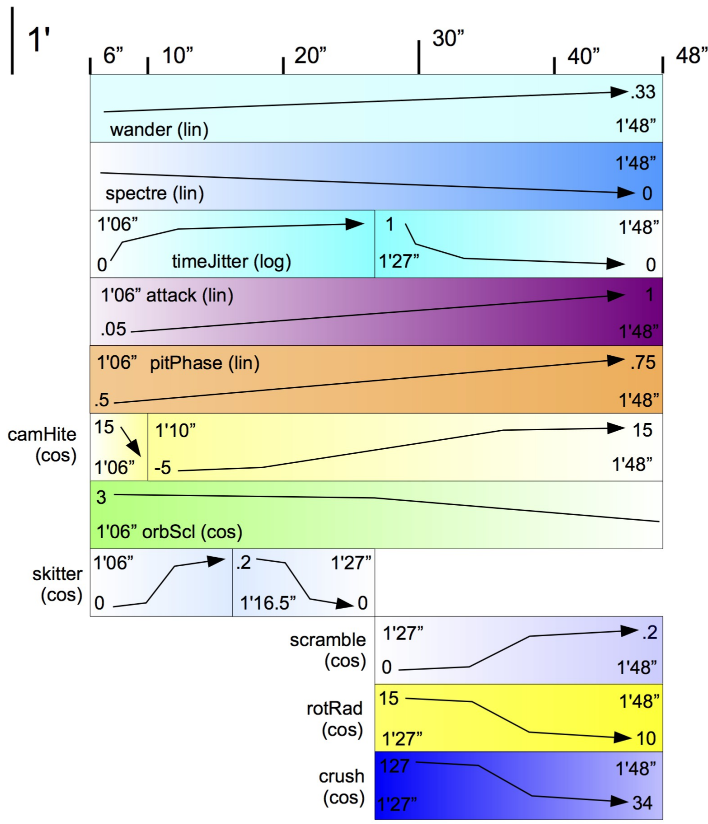
Cells activate with
2 or 3 active neighbors
Cells stay active with
3 or 4 active neighbors

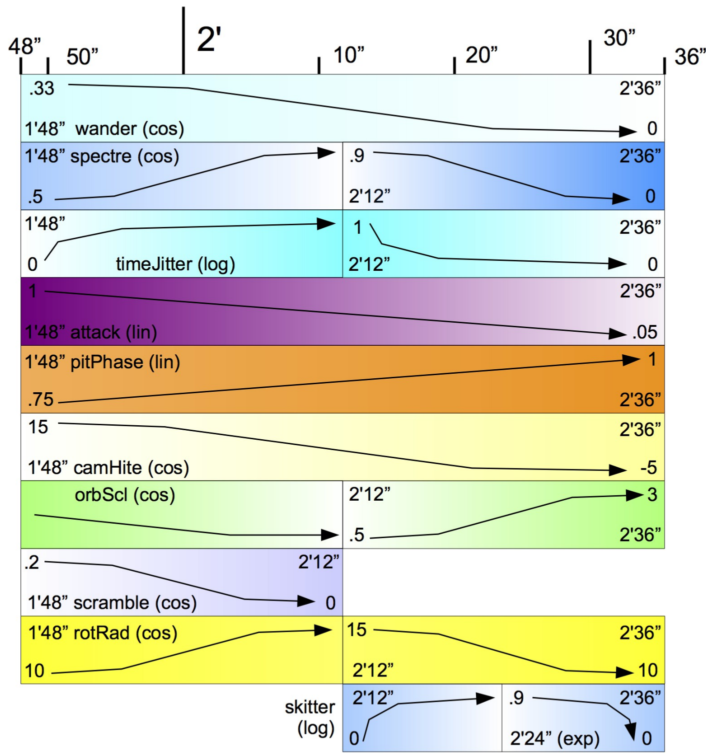


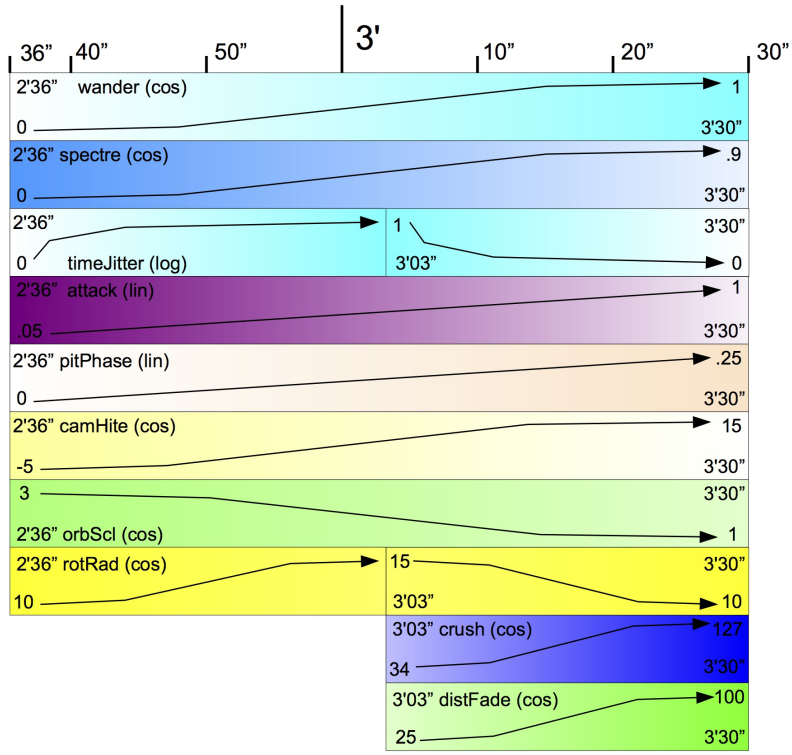
Other variables:
tempo: 3000 ms
lookAt: 4
decay: 1

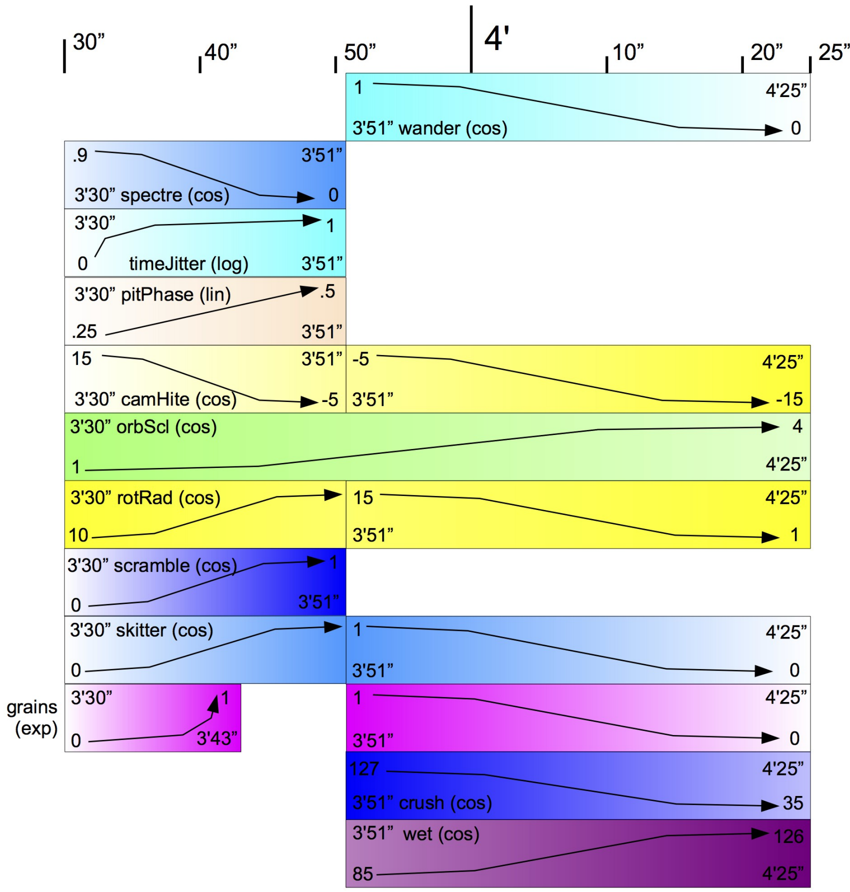
Movement III



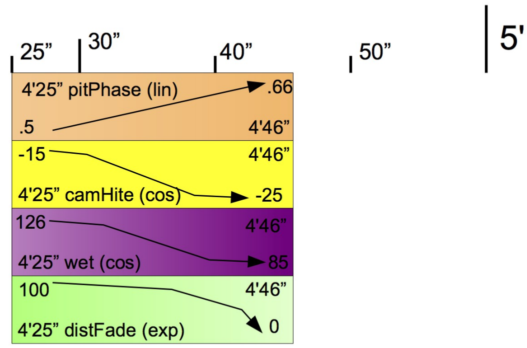

1'
6"
10"
20"
30"
40"
48"
wander (lin)
.33
1'48"
spectre (lin)
1'48"
0
timeJitter (log)
1'06"
0
1
1'27"
1'48"
0
1'06" attack (lin)
.05
1
1'48"
1'06" pitPhase (lin)
.5
.75
1'48"
camHite (cos)
15
1'06"
1'10"
-5
15
1'48"
3
1'06" orbScl (cos)
skitter (cos)
1'06"
0
.2
1'16.5"
1'27"
0
scramble (cos)
1'27"
0
.2
1'48"
rotRad (cos)
15
1'27"
1'48"
10
crush (cos)
127
1'27"
1'48"
34


48”
50”
2'
10”
20”
30”
36”
.33
2'36”
1'48” wander (cos)
0
1'48” spectre (cos)
.5
.9
2'36”
2'12”
0
1'48”
0
timeJitter (log)
1
2'36”
2'12”
0
1
2'36”
1'48” attack (lin)
.05
1'48” pitPhase (lin)
1
.75
2'36”
15
2'36”
1'48” camHite (cos)
-5
orbScl (cos)
2'12”
3
.5
2'36”
.2
2'12”
1'48” scramble (cos)
0
1'48” rotRad (cos)
10
15
2'36”
2'12”
10
skitter
(log)
2'12”
0
.9
2'36”
2'24” (exp)
0


36”
40”
50”
3'
10”
20”
30”
2'36” wander (cos)
0
1
3'30”
2'36” spectre (cos)
0
.9
3'30”
2'36”
0
timeJitter (log)
1
3'03”
3'30”
0
2'36” attack (lin)
.05
1
3'30”
2'36” pitPhase (lin)
0
.25
3'30”
2'36” camHite (cos)
-5
15
3'30”
3
2'36” orbScl (cos)
3'30”
1
2'36” rotRad (cos)
10
15
3'03”
3'30”
10
3'03” crush (cos)
34
127
3'30”
3'03” distFade (cos)
25
100
3'30”



30”
40”
50”
4'
10”
20”
25”
1
4'25”
3'51” wander (cos)
0
.9
3'51”
3'30” spectre (cos)
0
3'30”
1
0
timeJitter (log)
3'51”
3'30” pitPhase (lin)
.5
.25
3'51”
15
3'51”
-5
4'25”
3'30” camHite (cos)
-5
3'51”
-15
3'30” orbScl (cos)
4
1
4'25”
3'30” rotRad (cos)
15
4'25”
10
3'51”
1
3'30” scramble (cos)
1
0
3'51”
3'30” skitter (cos)
1
4'25”
0
3'51”
0
grains
(exp)
3'30”
1
0
3'43”
1
4'25”
3'51”
0
127
4'25”
3'51” crush (cos)
35
3'51” wet (cos)
126
85
4'25”


25”
30”
40”
50”
5'
4'25” pitPhase (lin)
.5
.66
4'46”
-15
4'46”
4'25” camHite (cos)
-25
126
4'46”
4'25” wet (cos)
85
100
4'46”
4'25” distFade (exp)
0

3

Instrumental score to *Ouroboros*

Instrumentation:

Flute
B♭ Clarinet
    doubling B♭ Bass Clarinet (with low concert B♭ extension)
Tenor Saxophone
    doubling Soprano Saxophone
C Trumpet
Percussion 1
    Vibraphone, Spring Coil, Quarter-tone Pipes
Percussion 2
    5-octave Marimba, Tam-tam, Bass drum
Piano (prepareable – temporary muting techniques will be applied to the strings)
Violoncello
Contrabass

Computer
    6 channel fixed and live digital audio media
    720p digital video media

All instruments should be subtly amplified and reverberated to blend with the digital audio media.

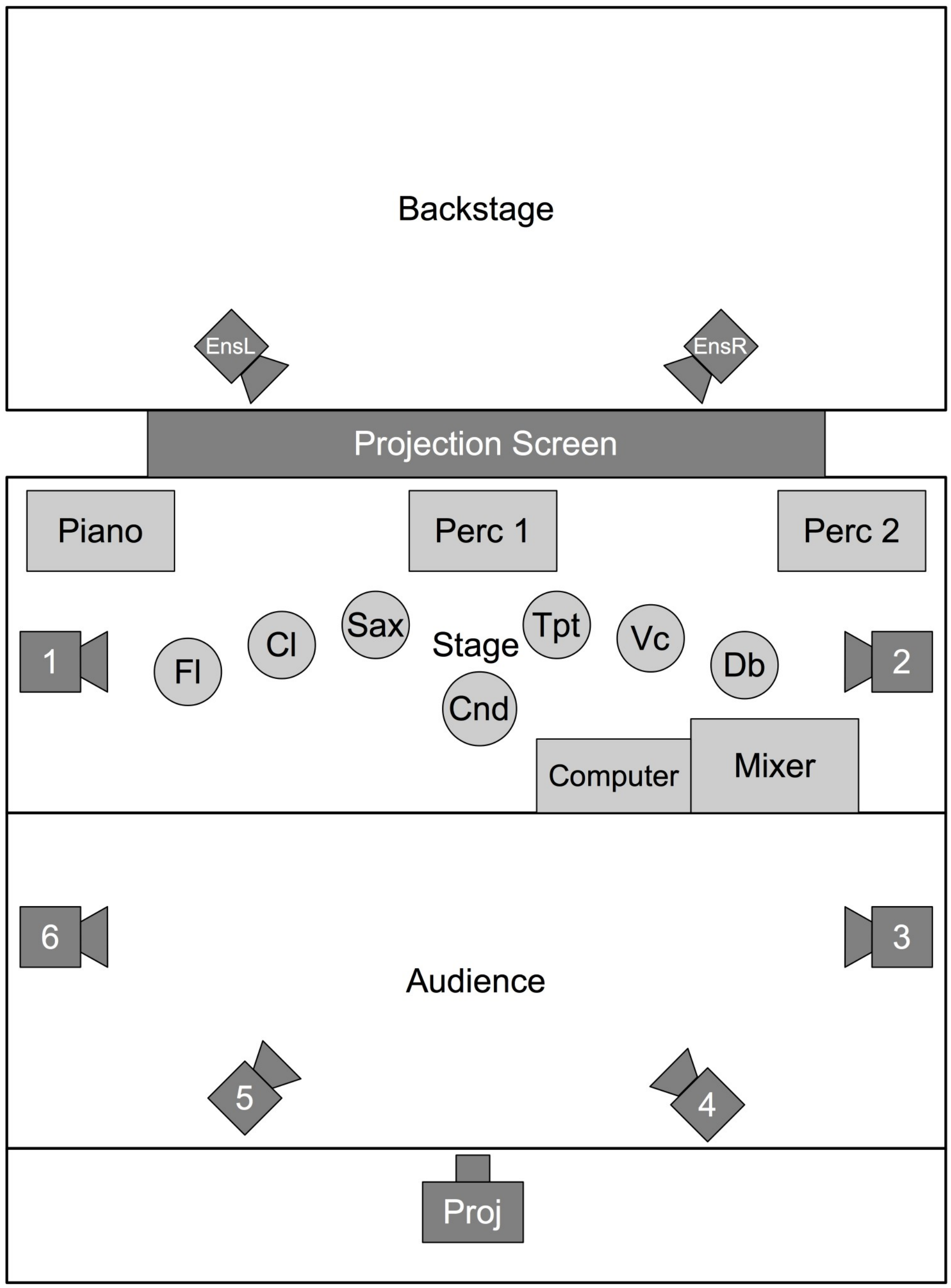
C Score

Total Duration: ca. 15'00"

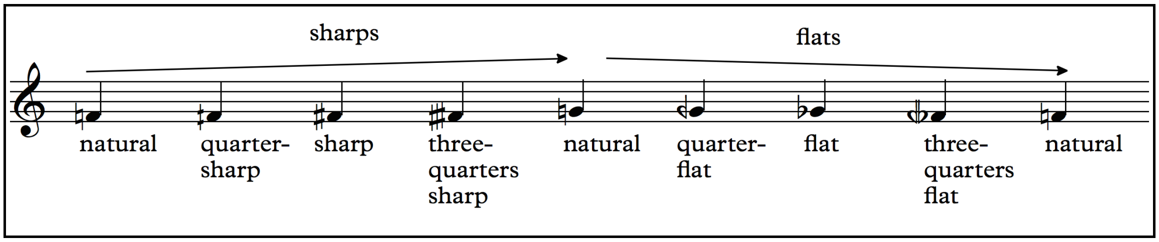
Technical requirements:

10 microphones, stands, and cables
    (one for each instrumentalist, with two on the piano)
16 input, 8 discrete output minimum mixer
22.5° offset octophonic loudspeaker setup, cabling and mounting
    Front left....................reinforcement for left side of ensemble
    Front right..................reinforcement for right side of ensemble
    Front left side.............computer channel 1
    Front right side...........computer channel 2
    Back right side...........computer channel 3
    Back right...................computer channel 4
    Back left.....................computer channel 5
    Back left side..............computer channel 6
1 channel headphone amplifier, providing click-track for conductor
720p minimum resolution projector, cabling and mounting

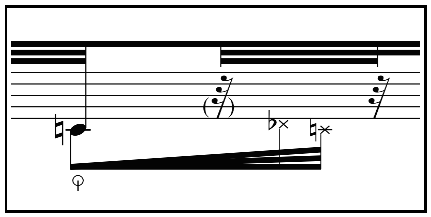
Stage and technical setup:



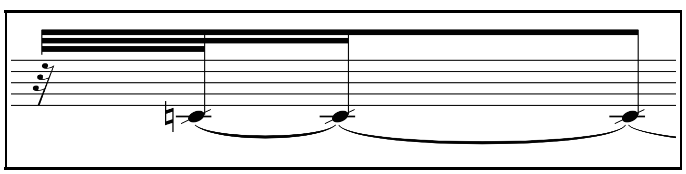
Guide to Unusual Notation and Techniques:



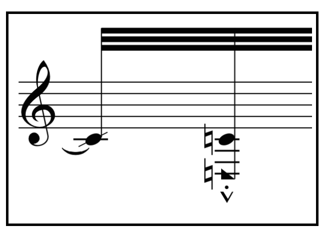
All instruments: the *quarter tone accidental system* used in *Ouroboros* is pictured above.



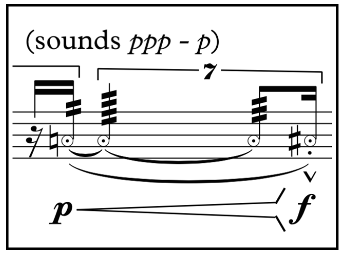
All instruments: *feathered beaming,* smoothly increasing or decreasing numbers of beams, indicates increasing or decreasing speeds of figures, out of tempo (as grace notes).
All winds: *key clicks* are indicated by x note heads.
Flute, clarinet, saxophone: *slap-tongue* is indicated by a snap-pizzicato.



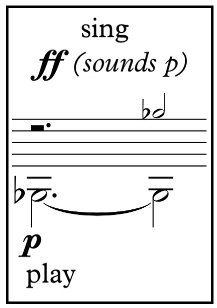
Flute: *pitched-air sound*, indicated by regular note heads with slashes.



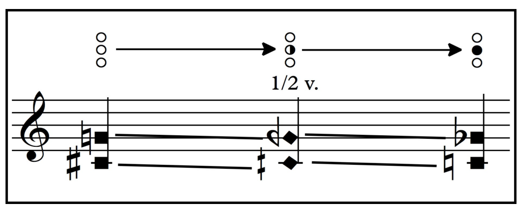
Flute: *tongue-ram*, indicated by a staccato-marcato combination and both regular and triangular note heads. The regular note head indicates the fingered pitch, while the triangular note head indicates the sounding pitch (a minor seventh below).



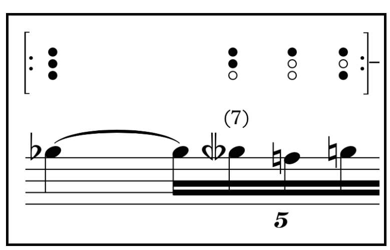
All winds: an *air-only* sound is indicated by circular note heads with a single dot in the middle. Dynamics shown should guide physical exertion, while the actual sounding dynamic will be several levels lower.



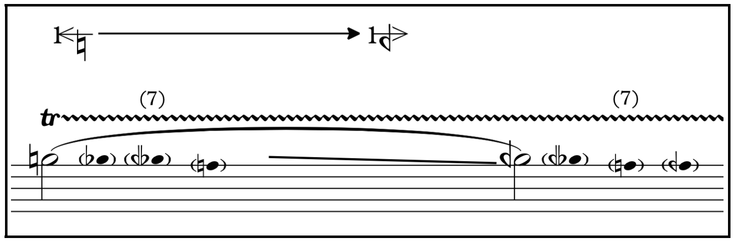
All winds: *singing while playing* is indicated with the presence of small note heads, indicating sung pitches, above or below normal note heads, which are the played pitches.



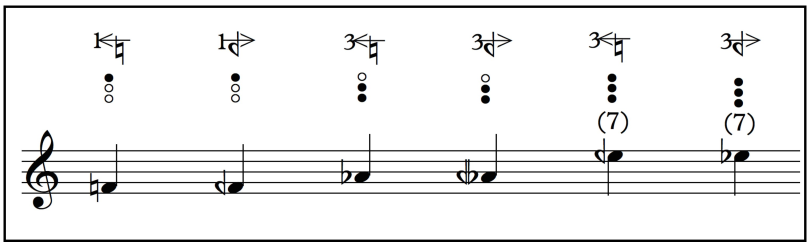
Trumpet: *split-tone multiphonics* are indicated by two square note heads and a fingering used to produce those two partials. *Half-valve glissandi* are indicated with half-filled circles in the fingerings, and arrows indicating smooth changes. If an *intermediary stage of valve depression* should be dwelt upon, it is indicated by diamond note heads.



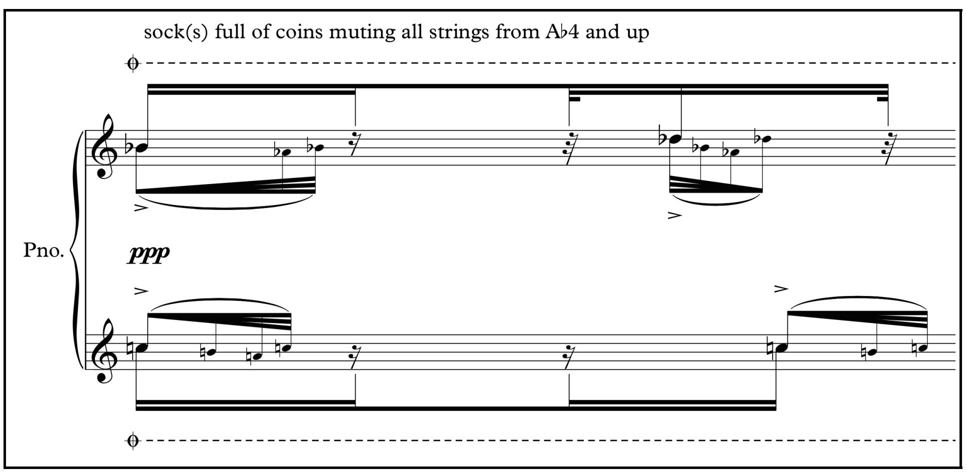
Trumpet: *rapid-fingering groupings* are indicated with fingerings enclosed with repeat signs, followed by an extension showing how long to repeat the fingerings. These occasionally transform into trills with three or four different notes (see below).



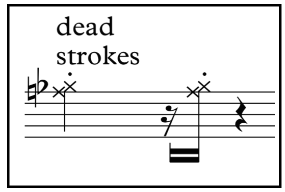
Trumpet: *trill auxiliary notes* are indicated by parenthetical note heads. *Quarter-tone glissandi* of selected notes within trills may be obtained by extending either the first or third valve slide.



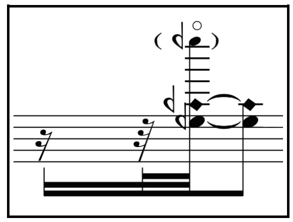
Trumpet: *trumpet-specific quarter tones techniques* come in two versions: those achieved by extending either the first or third valve slides, or alternatively by using the flat seventh harmonic. Combining the seventh harmonic with further flattening can bring pitches back into equal temperament.



Piano: *string muting* is marked with the mute symbol and a dotted extension showing muting duration. This technique is achieved with socks of coins, or, if unmarked, the pianist's fingers.



Percussion: *dead strokes* are marked with x note heads.



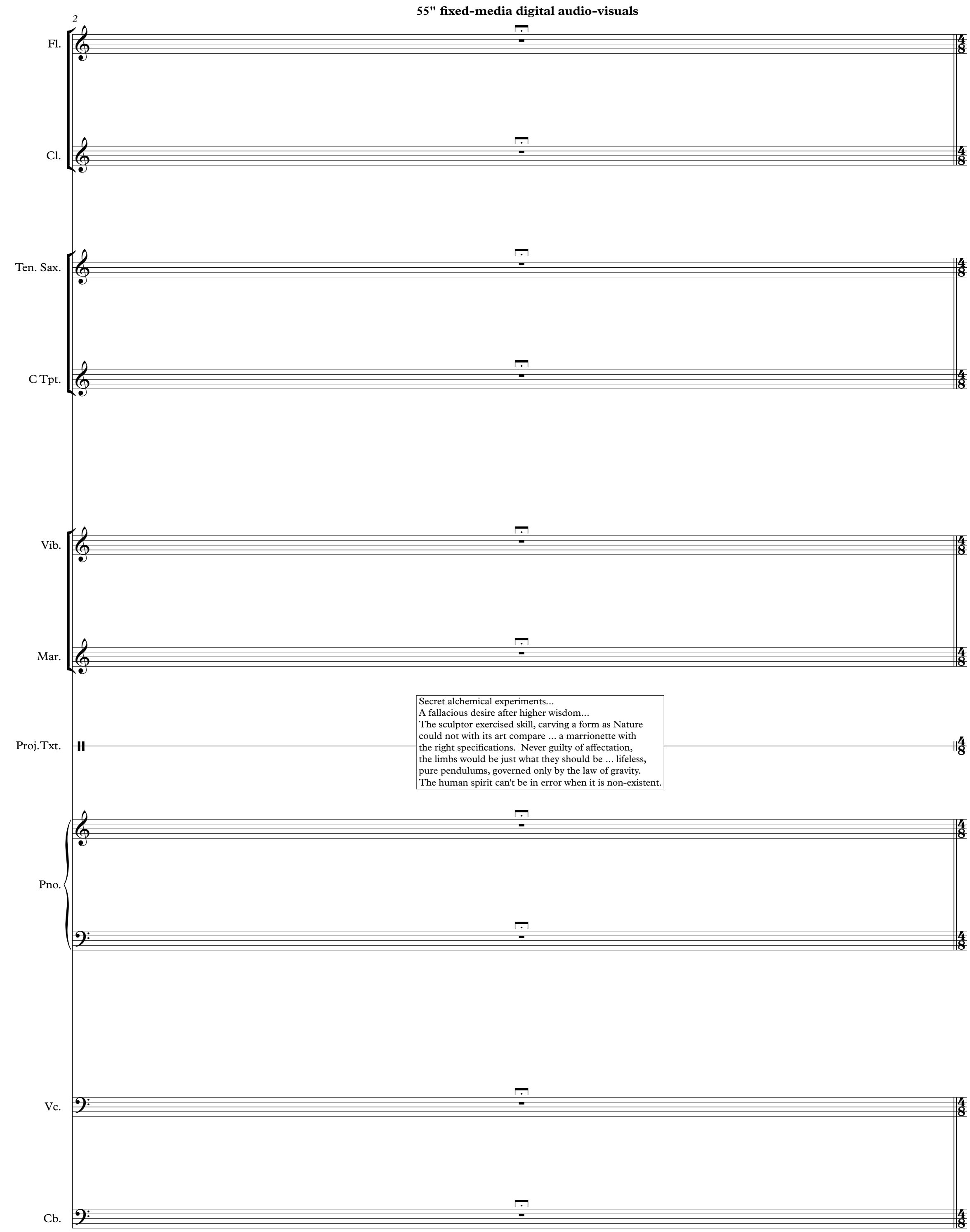
Strings: *artificial harmonics* are notated with a regular note head for the stopped pitch, a diamond note head for the lightly-touched node a fourth above, and a parenthetical note head, marked with the harmonic symbol, for the sounding pitch.

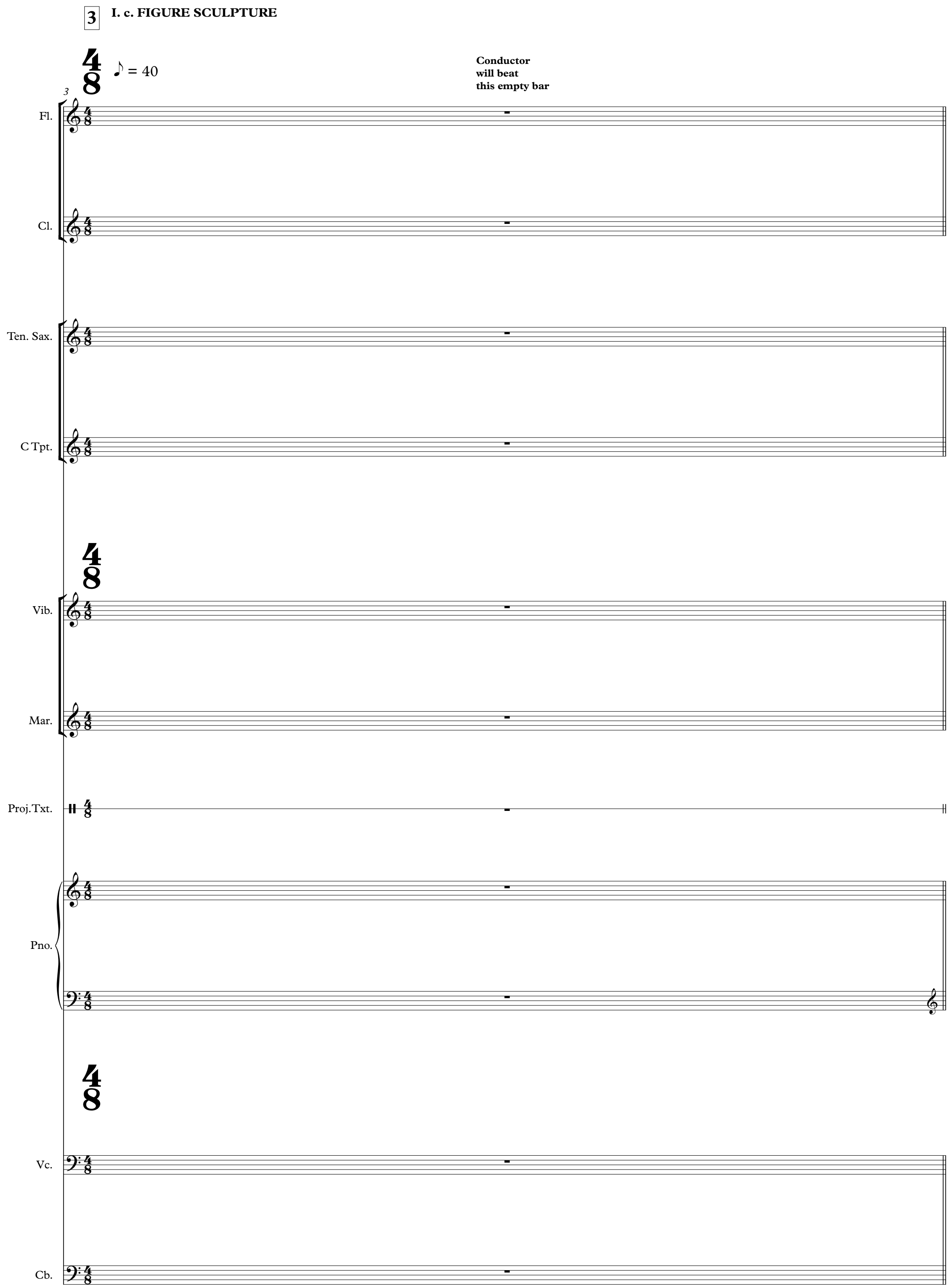
Score in C

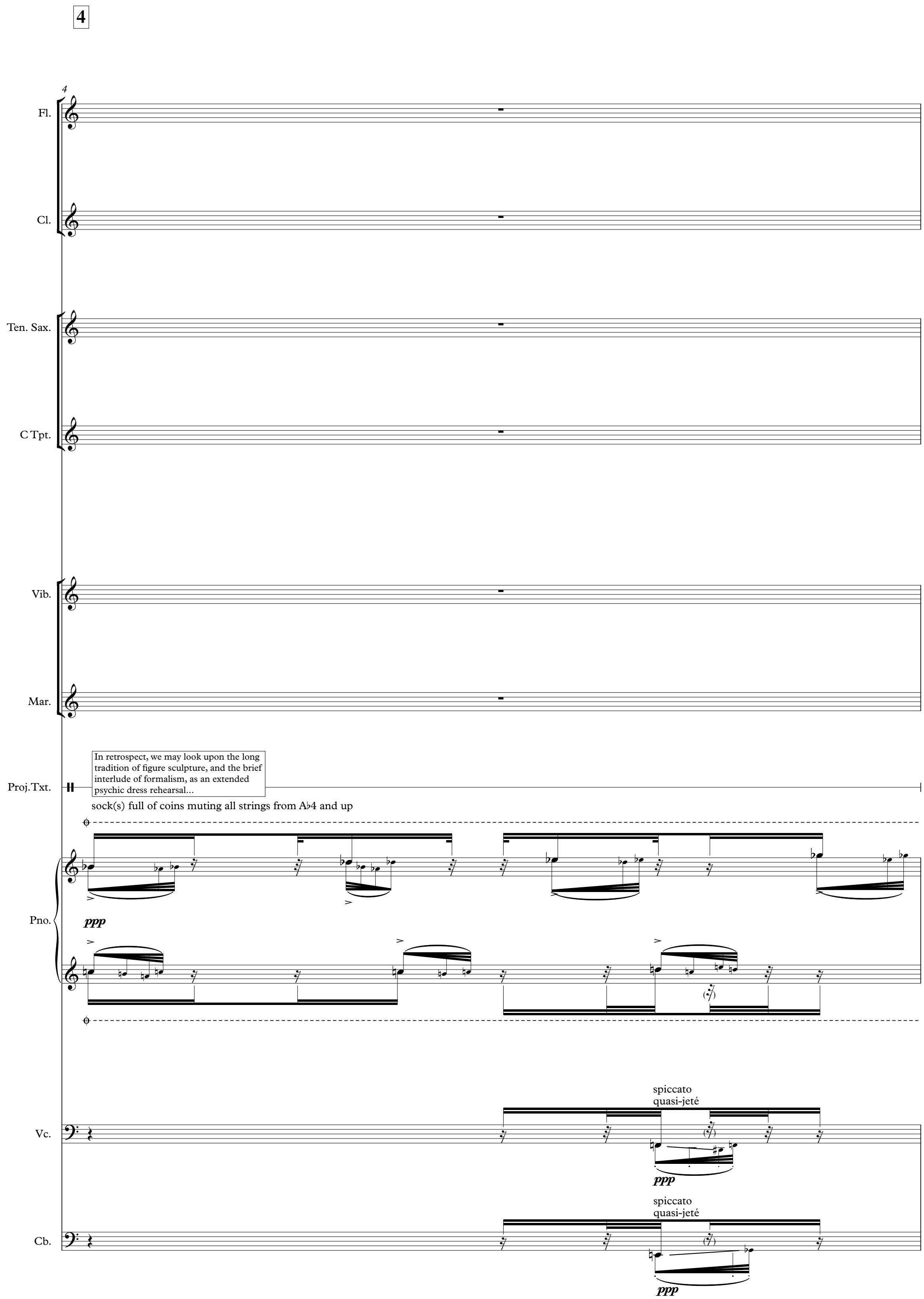
Ouroboros

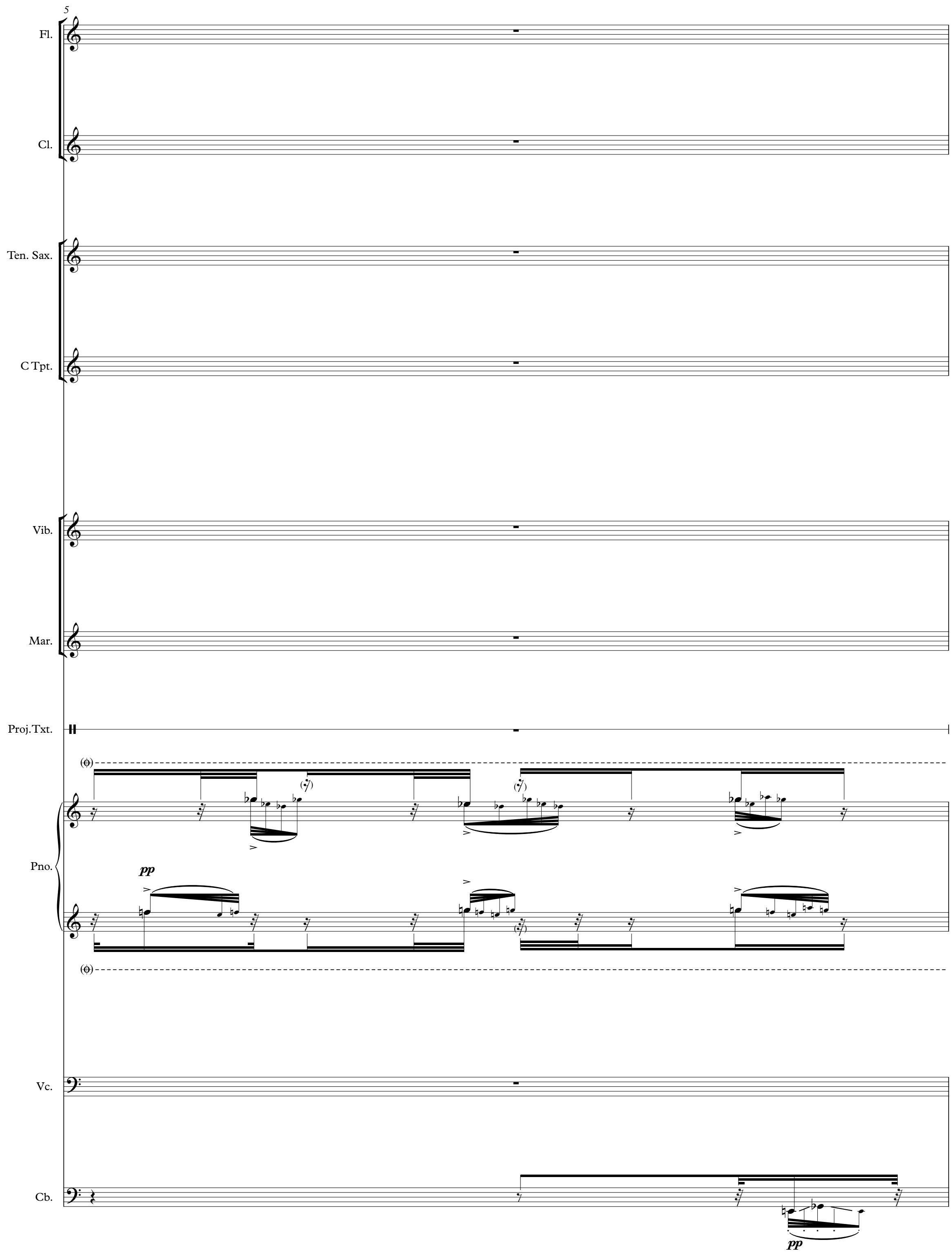
Paul Hembree

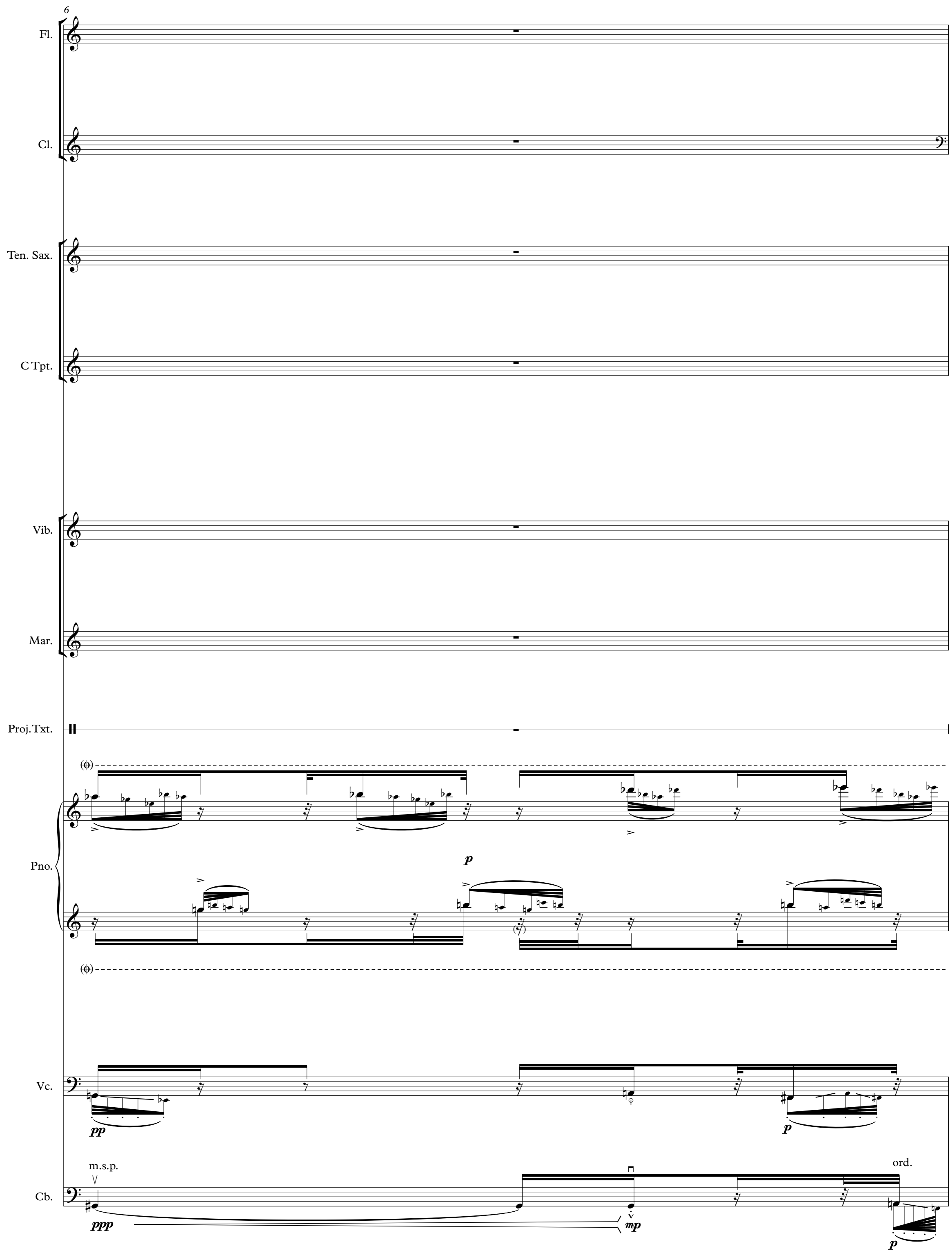
2 **I. b. SECRET ALCHEMY**

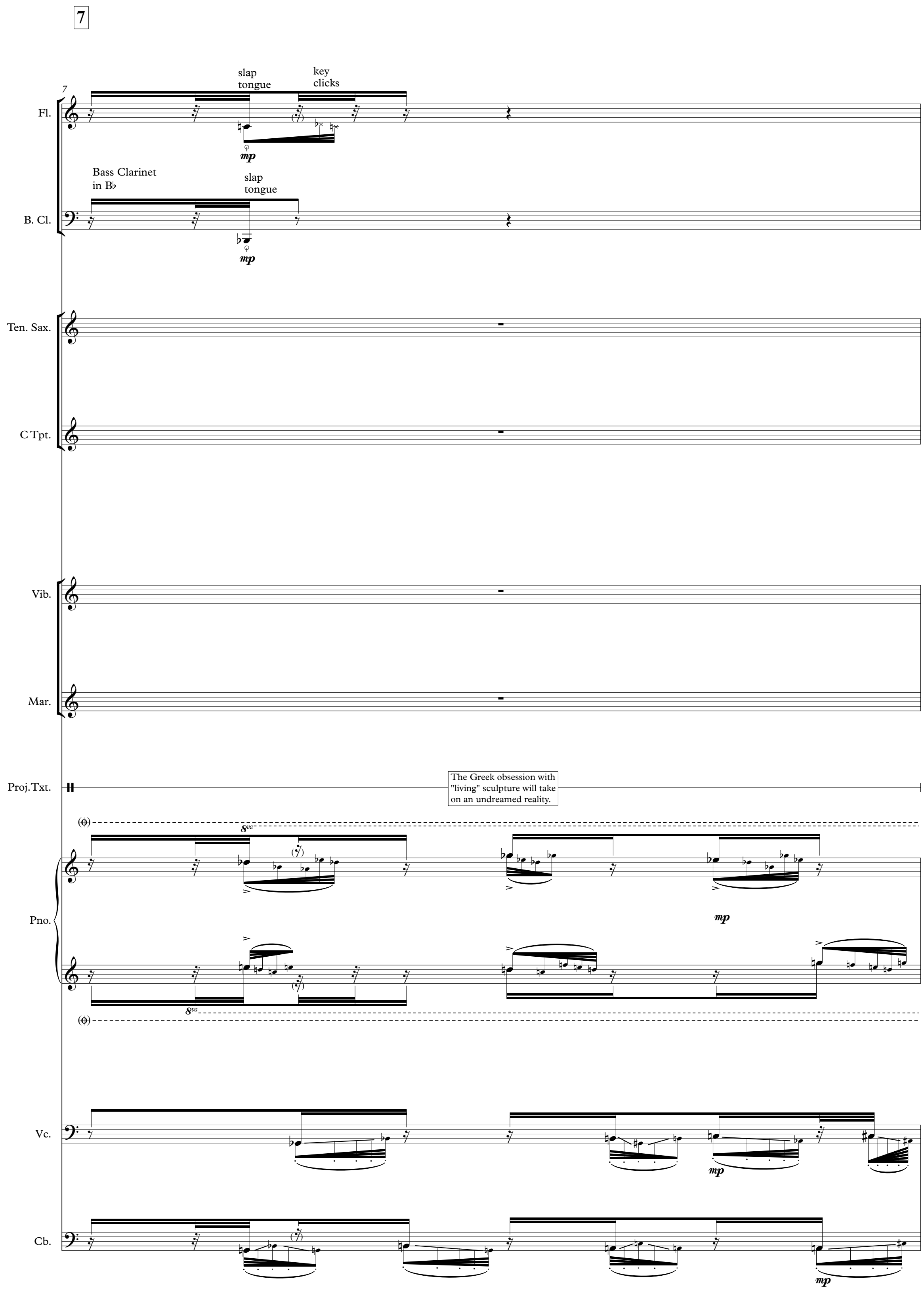



3
I. c. FIGURE SCULPTURE
4/8
♪ = 40
Conductor
will beat
this empty bar
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.

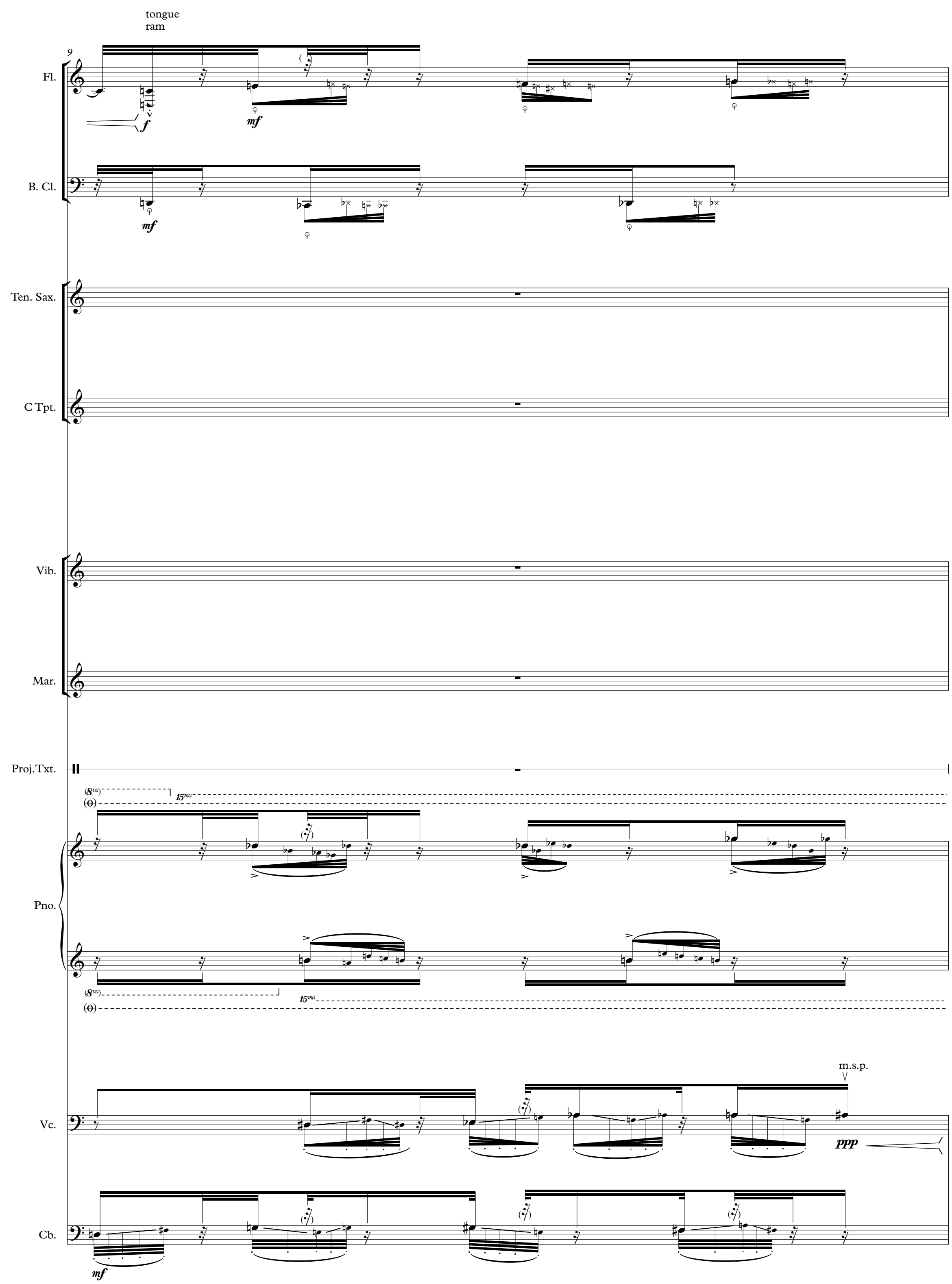

4
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
In retrospect, we may look upon the long tradition of figure sculpture, and the brief interlude of formalism, as an extended psychic dress rehearsal...
sock(s) full of coins muting all strings from A♭4 and up
Pno.
ppp
Vc.
spiccato
quasi-jeté
ppp
Cb.
spiccato
quasi-jeté
ppp

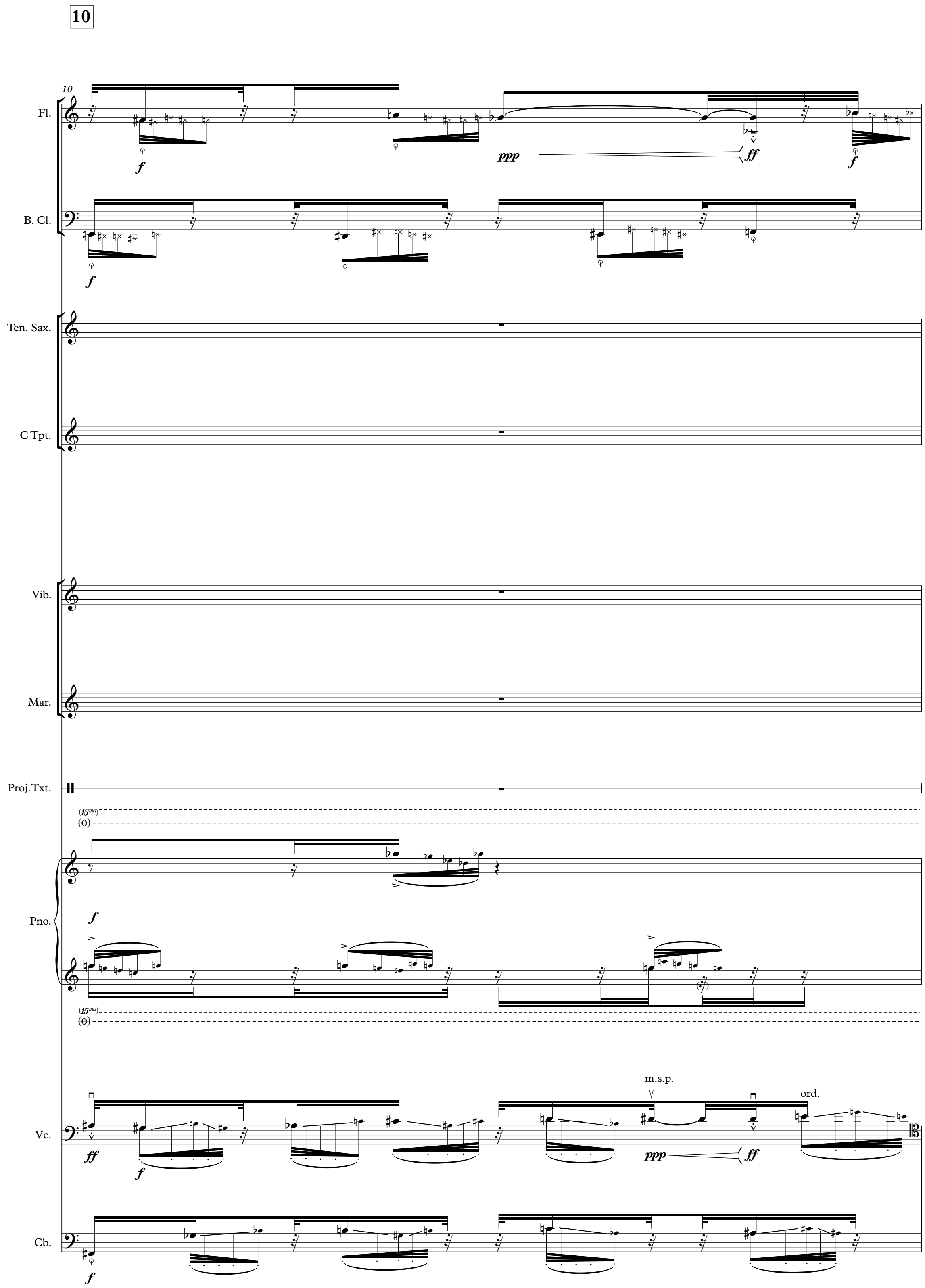

5
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
pp
Vc.
Cb.
pp

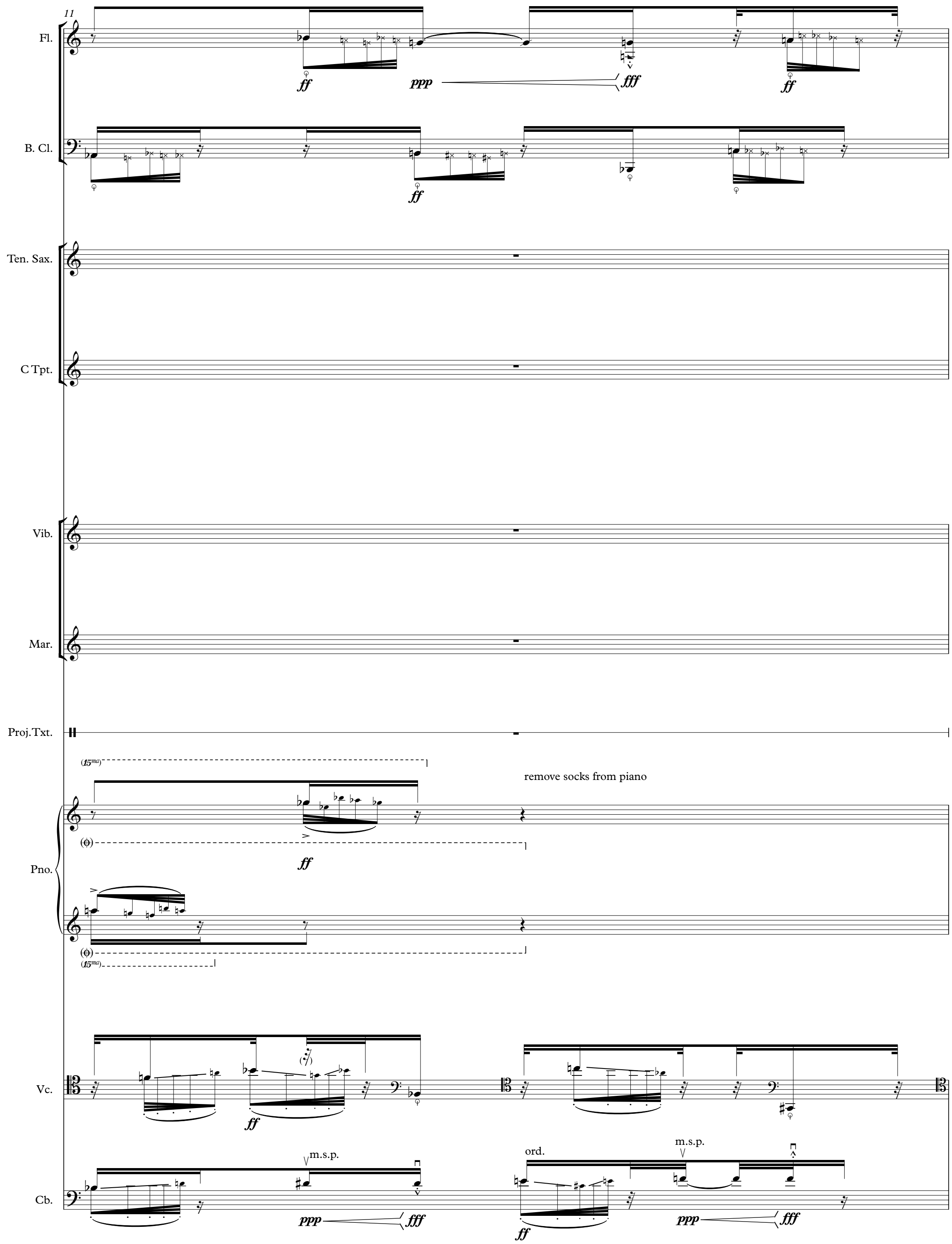

6
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
p
Vc.
pp
p
m.s.p.
Cb.
ppp
mp
ord.
p

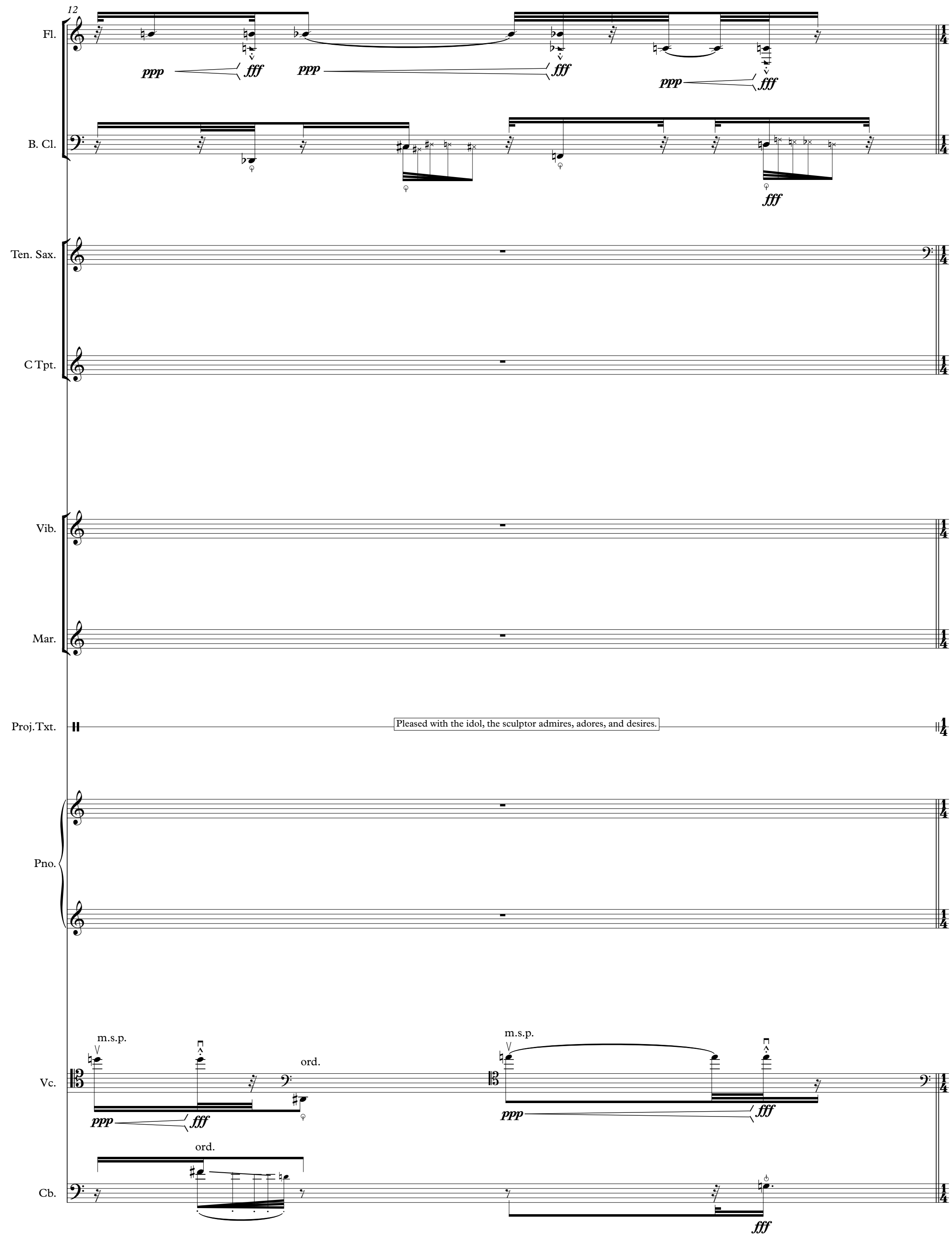

7
7
slap
tongue
key
clicks
Fl.
mp
Bass Clarinet
in B♭
slap
tongue
B. Cl.
mp
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
The Greek obsession with
"living" sculpture will take
on an undreamed reality.
Pno.
mp
Vc.
mp
Cb.
mp


8
Fl.
pitched
air
ppp
B. Cl.
key
clicks
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
mf
Vc.
mf
Cb.
m.s.p.
ppp
mf


tongue
ram
9
Fl.
f
mf
B. Cl.
mf
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
(8va)
15ma
Pno.
(8va)
15ma
m.s.p.
Vc.
ppp
Cb.
mf


10
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
f
ppp
ff
m.s.p.
ord.
(15ma)


11
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
remove socks from piano
Vc.
Cb.
m.s.p.
ord.
m.s.p.

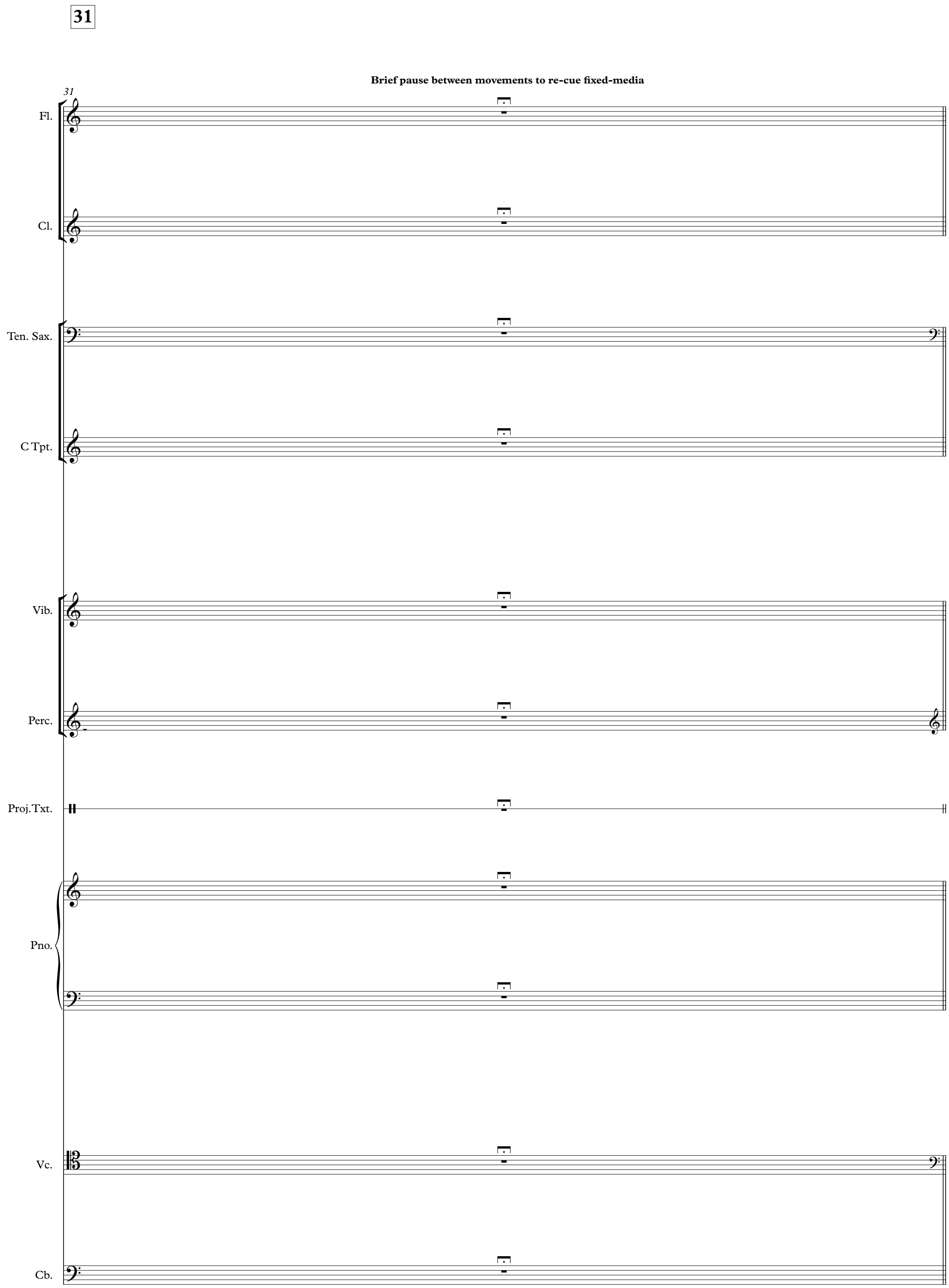

12
Fl.
ppp
fff
ppp
fff
ppp
fff
B. Cl.
fff
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pleased with the idol, the sculptor admires, adores, and desires.
Pno.
Vc.
m.s.p.
ord.
m.s.p.
ppp
fff
ppp
fff
Cb.
ord.
fff

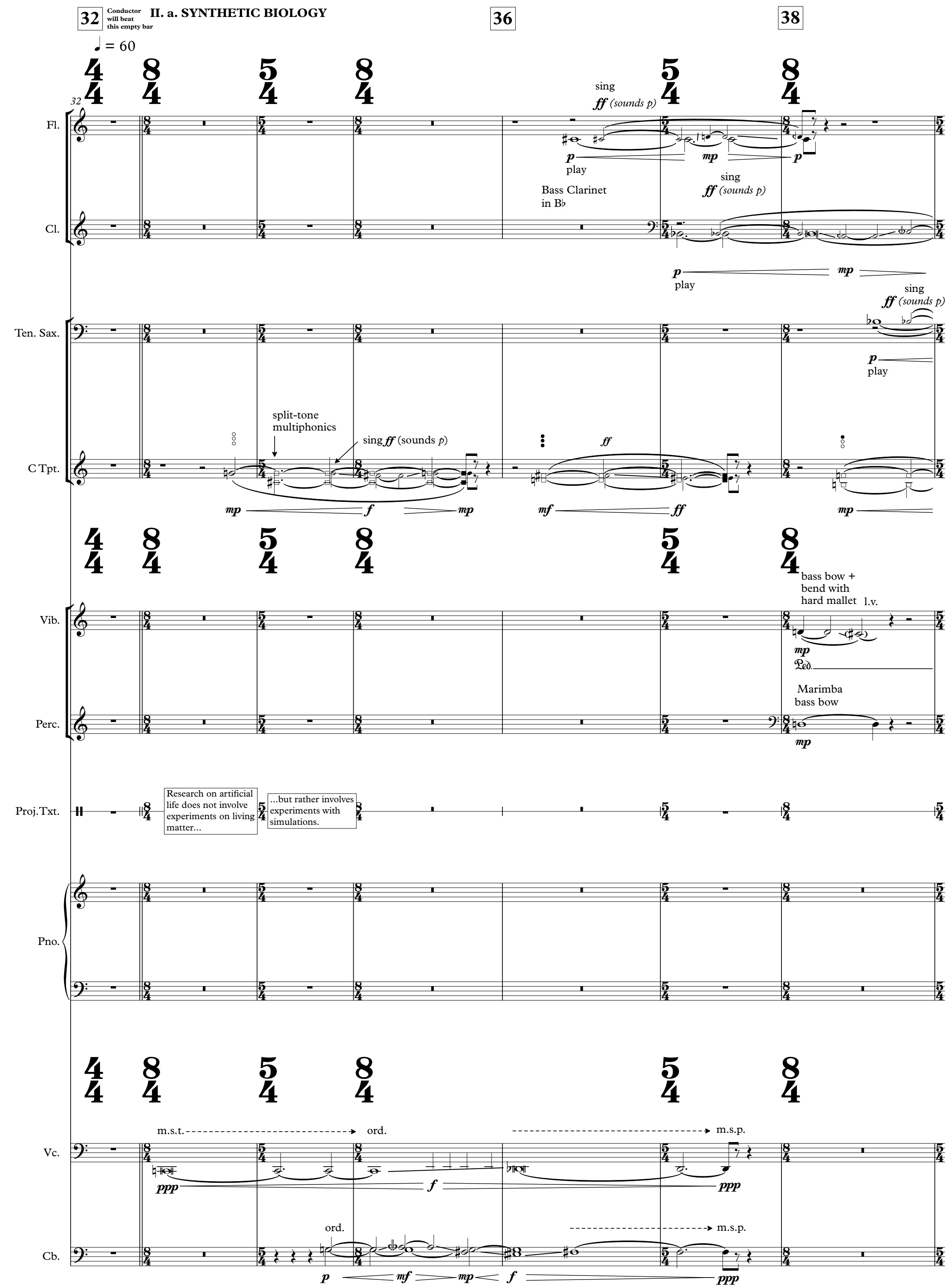

13
I. d. SPECTACLES
17
♩ = 60
Fl.
B. Cl.
To Cl.
Clarinet in B♭
Ten. Sax.
Tenor Saxophone
fl.t.
C Tpt.
fl.t.
*. Tuning alterations to particular fingerings with the 1st and 3rd valve slides are shown with arrows attached to each valve number. Quarter-flat signs attached to arrows moving away from the number mean to extend the numbered valve, lowering the pitch by a quarter-tone. Natural signs attached to arrows indicate default, unaltered pitch. Long arrows connecting multiple valve positions indicate gradual changes.
Vib.
Vibraphone
slow motor
Mar.
Percussion
tam-tam
bass drum
Proj.Txt.
Pno.
Vc.
Cb.

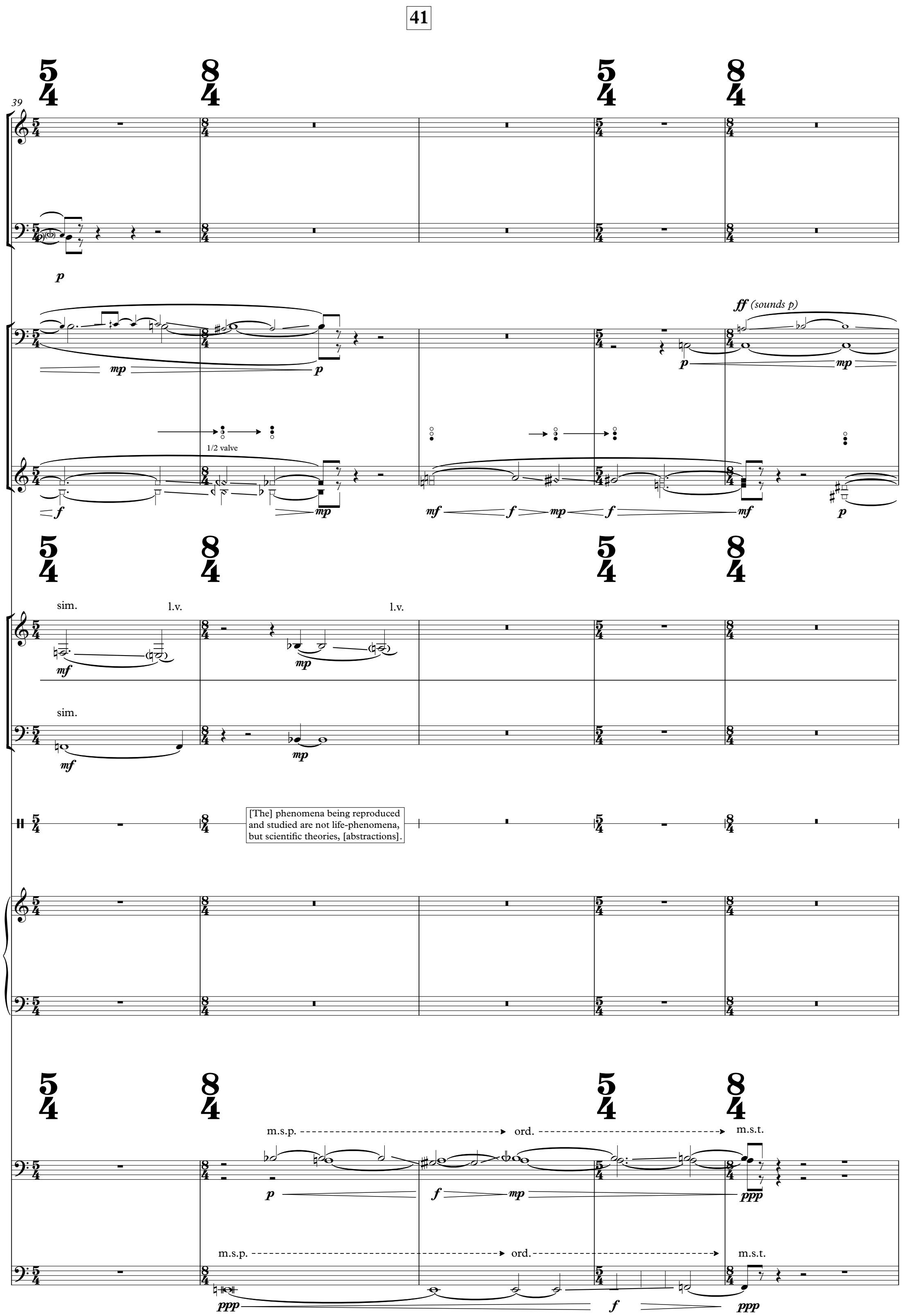

20
18
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Perc.
tam-tam
bass bow
To Mar.
Marimba
Proj.Txt.
It caught
the carver
in its deceit.
Pno.
Vc.
Cb.

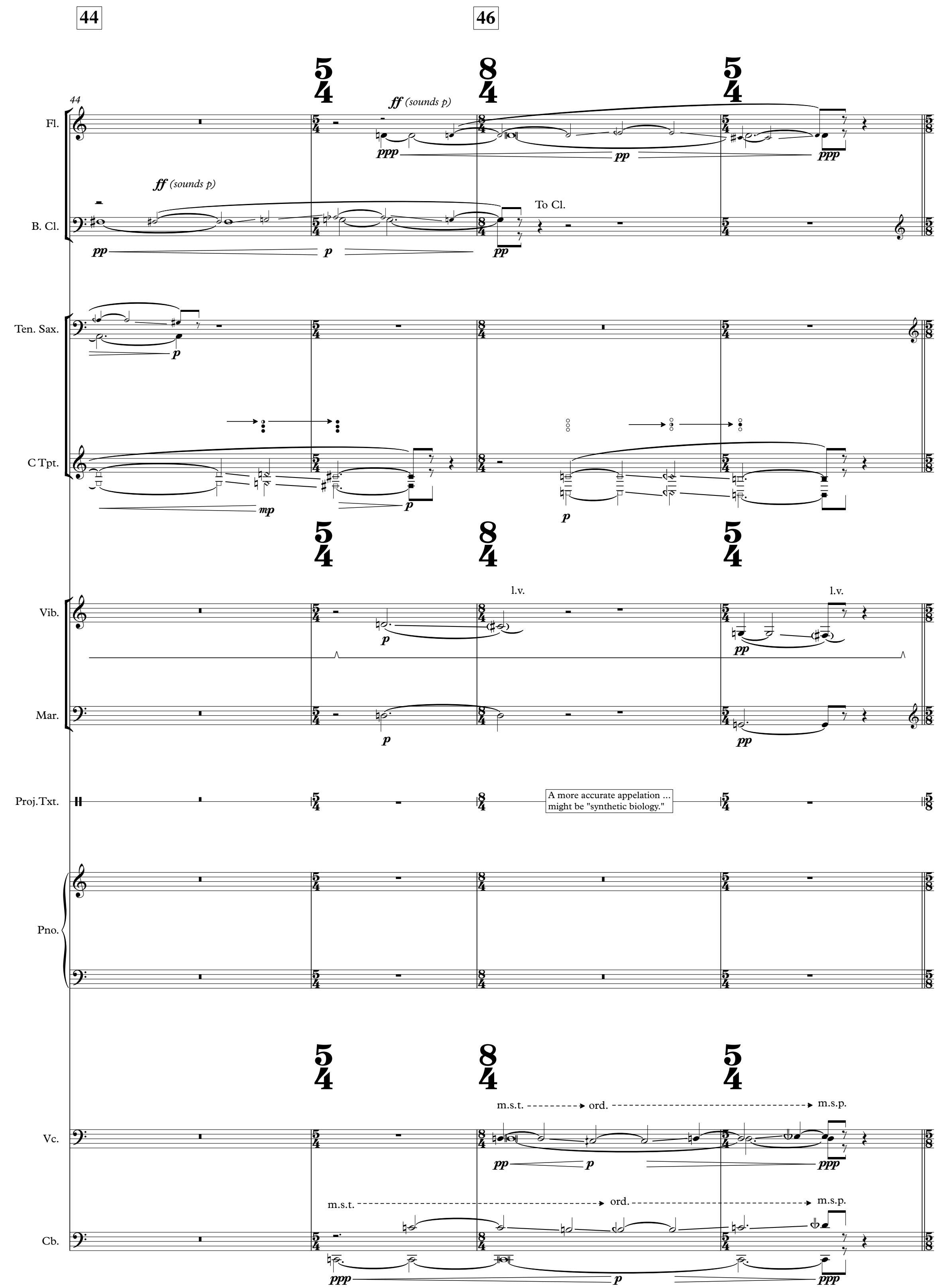

23
26
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
fl.t.
1/2 valve
(7)*
*. (7): Accompanies notes that are the 7th partial on any particular fingering.
Their tuning is approximated with a quarter-tone, and no adjustments
with the 1st or 3rd valve slide are necessary to acheive these quarter tones.
They may be further altered with 1st or 3rd valve slide adjustments, however.
Percussion
bass drum
super-ball mallet
tam-tam
beater
Clutching with
burning arms,
and hands as
cold as ice.
Flushed
with blood.


29
27
rit.
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Perc.
tam-tam
bass bow
To Mar.
Proj.Txt.
Pno.
Vc.
Cb.


31
Brief pause between movements to re-cue fixed-media
31
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Perc.
Proj.Txt.
Pno.
Vc.
Cb.


32
Conductor will beat this empty bar
II. a. SYNTHETIC BIOLOGY
36
38
♩ = 60
Fl.
sing
ff (sounds p)
p
play
mp
p
Cl.
Bass Clarinet in B♭
sing
ff (sounds p)
p
play
mp
Ten. Sax.
sing
ff (sounds p)
p
play
C Tpt.
split-tone multiphonics
sing ff (sounds p)
mp
f
mp
ff
mf
ff
mp
Vib.
bass bow + bend with hard mallet
l.v.
mp
Perc.
Marimba bass bow
mp
Proj.Txt.
Research on artificial life does not involve experiments on living matter...
...but rather involves experiments with simulations.
Pno.
Vc.
m.s.t.
ord.
m.s.p.
ppp
f
ppp
Cb.
ord.
m.s.p.
p
mf
mp
f
ppp


41
39
Fl.
B. Cl.
Ten. Sax.
ff (sounds p)
1/2 valve
C Tpt.
sim.
l.v.
Vib.
Mar.
Proj.Txt.
[The] phenomena being reproduced
and studied are not life-phenomena,
but scientific theories, [abstractions].
Pno.
m.s.p.
ord.
m.s.t.
Vc.
Cb.


44
46
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
ff (sounds p)
To Cl.
l.v.
A more accurate appelation ...
might be "synthetic biology."
m.s.t.
ord.
m.s.p.


48
II. b. ARIA
51
♩ = 40
(♪ = 80)
Fl.
Clarinet in B♭
Cl.
Ten. Sax.
fl.t.
sim.
C Tpt.
*. Repeat signs enclosing groups of fingerings indicate rapid figures that are realizable through repetitions of simple groups of fingerings.
Vib.
Mar.
Proj.Txt.
The advantage of being weightless. Not afflicted with the inertia of matter...
Pno.
m.s.p.
Vc.
Cb.


54
52
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
Percussion
spring coil
l.v.
Ped.
s.p.
s.t.


57
59
♩ = 60
Fl.
Cl.
Ten. Sax.
C Tpt.
Vibraphone
dead
strokes
Perc.
Mar.
Proj.Txt.
In the heavens,
the orb of day, speaks...
mute with hand
Pno.
m.s.p.
Vc.
m.s.p.
Cb.


62
65
Fl.
Cl.
Ten. Sax.
C Tpt.
Percussion
spring coil
l.v.
To Vib.
Vib.
Mar.
Proj.Txt.
Propelled into the air
clear and piercing
Pno.
s.p.
Vc.
m.s.t.
Cb.


67
70
66
Fl.
Cl.
Ten. Sax.
C Tpt.
Perc.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
8va
fl.t.
sim.
dead
strokes
All that sings and resounds,
sighs in turn... trembles...
s.p.


73
II. c. DANCE
75
= 90
Fl.
Cl.
Ten. Sax.
To Sop. Sax.
C Tpt.
Vibraphone
Perc.
Mar.
Proj.Txt.
Glance against the ground only lightly
through this momentary check, renew the swing of limbs
sim.
Pno.
ord.
Vc.
Cb.

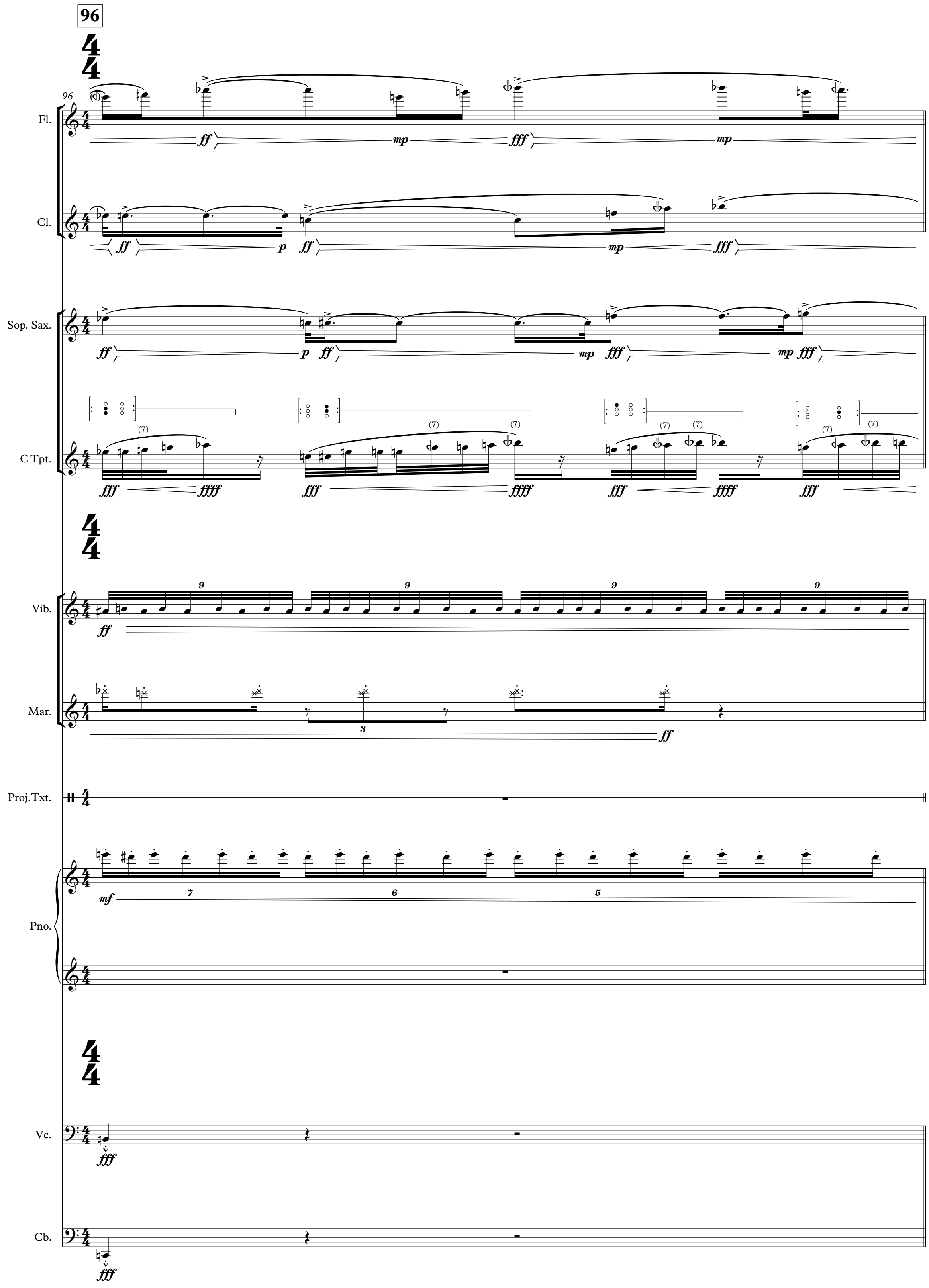

77
81
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
m.s.p.
m.s.p.


83
82
Fl.
Cl.
Soprano Saxophone
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
They are only pendulums, and follow mechanically of their own accord.
Pno.
Vc.
Cb.
m.s.p.
o.p.
ord.


86
89
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
ord.
m.s.p.
o.p.
ppp
p
mp
mf
f
ff


91
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
When the centre of gravity
is moved in a straight line,
the limbs describe curves...
Pno.
ord.
o.p.
Vc.
ord.
o.p.
Cb.


94
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Shaken in a haphazard way,
they fall into a kind of ... dance.
Pno.
Vc.
m.s.p.
Cb.
m.s.p.

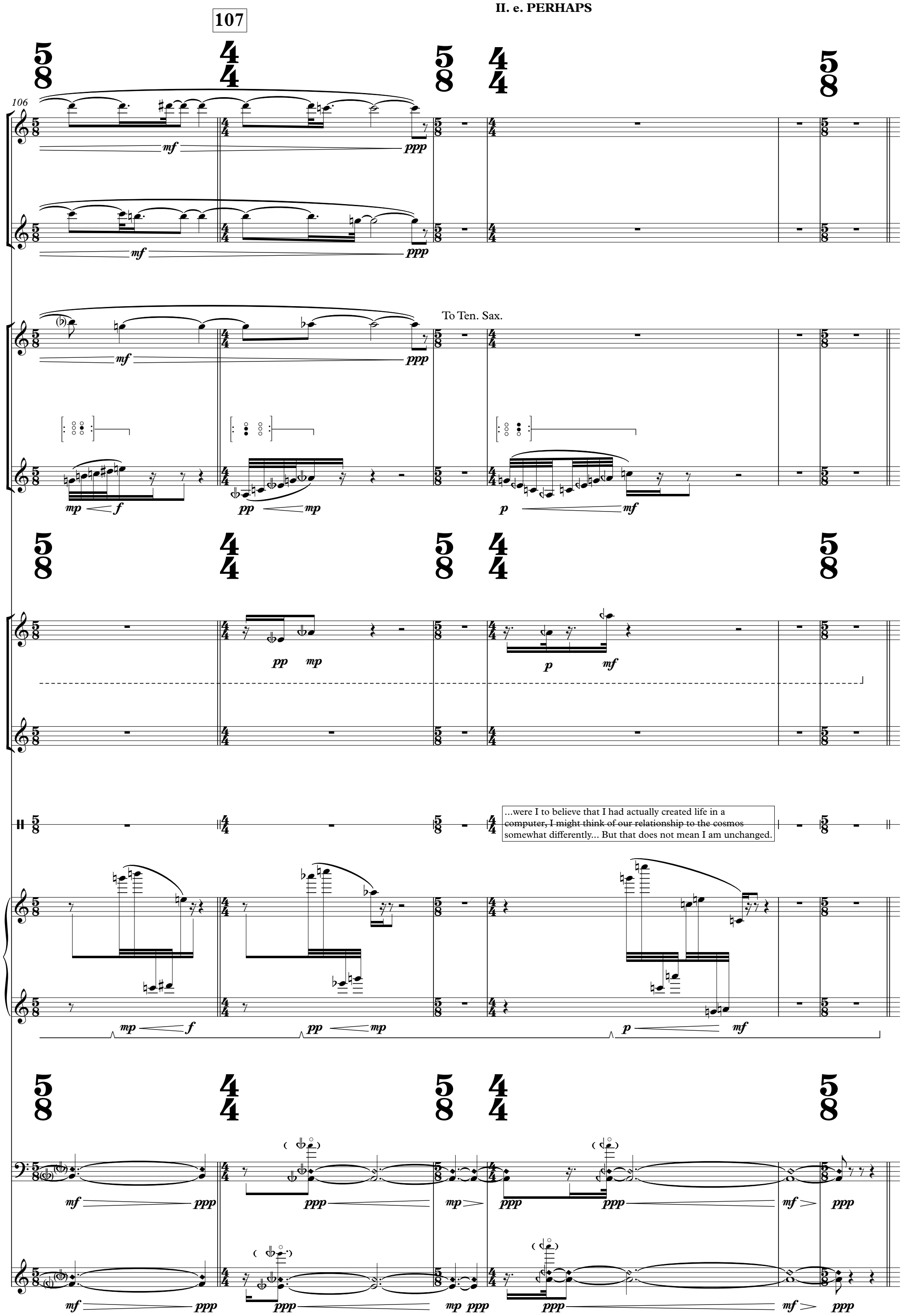

96
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.

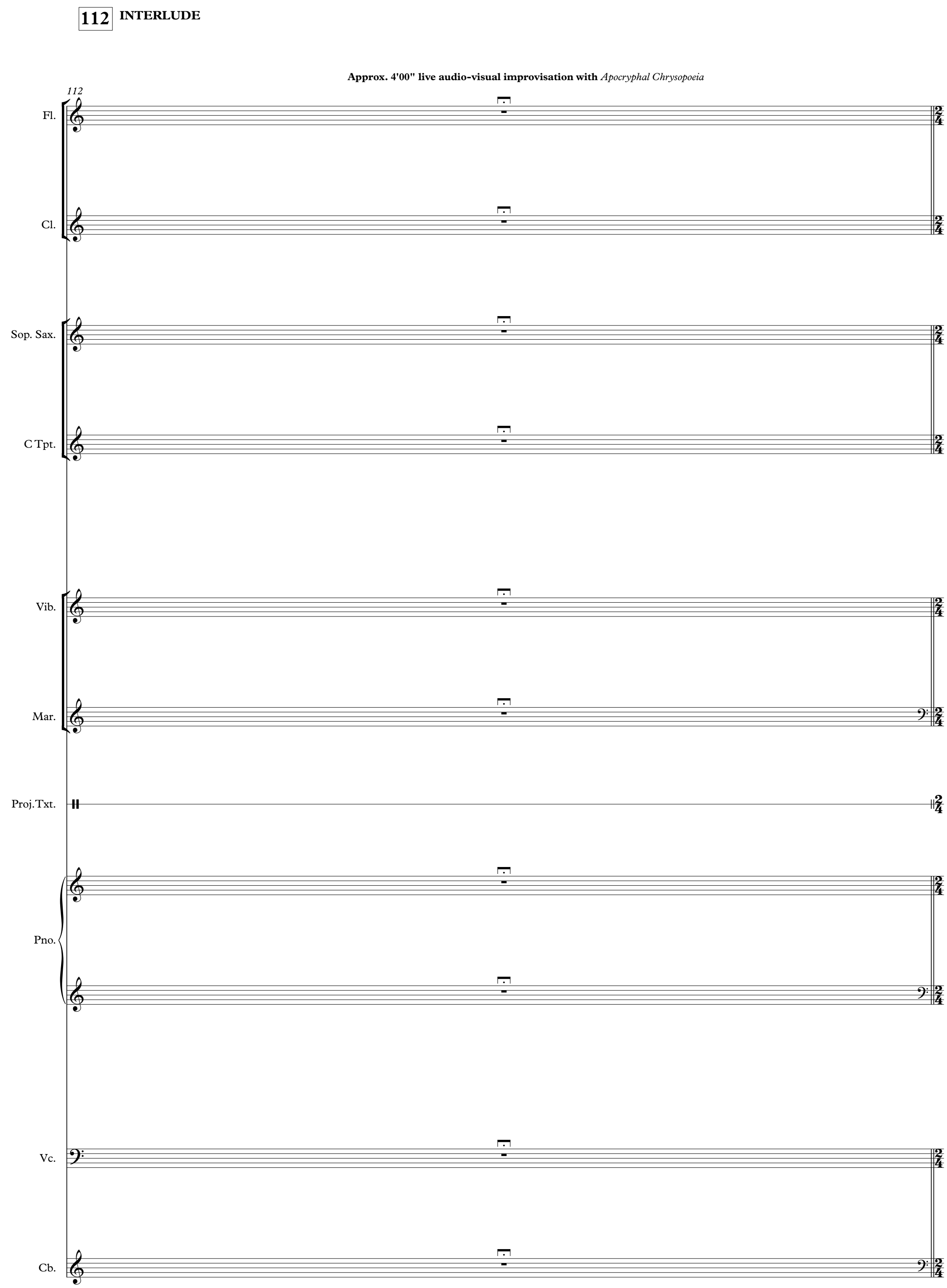
97 II. d. CATALYTIC RELAYS


99
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
ppp
f
mp
p
mf
ff
fff


102
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
But it is never a closed system, instead
a catalytic network of relays connecting one analog domain to another.
Pno.
Vc.
Cb.

II. e. PERHAPS


107
106
Fl.
Cl.
Sop. Sax.
To Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
...were I to believe that I had actually created life in a computer, I might think of our relationship to the cosmos somewhat differently... But that does not mean I am unchanged.
Pno.
Vc.
Cb.


112 INTERLUDE
Approx. 4'00" live audio-visual improvisation with Apocryphal Chrysopoeia
112
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.


113
III. a. THE CHERUBIM
117
♩ = 40
Conductor
will beat
this empty bar
Fl.
Cl.
Tenor
Saxophone
fl.t.
Sop. Sax.
C Tpt.
Vibraphone
Vib.
Mar.
Proj.Txt.
We've eaten of the tree of knowledge
paradise is locked and bolted
cherubim stand
behind us
Pno.
Vc.
Cb.
o.p.
ord.
mp p mf f pp ppp


119
121
Fl.
Cl.
Ten. Sax.
harmon mute stem in
C Tpt.
Vib.
Mar.
Proj.Txt.
We have to journey round the world...
Pno.
o.p.
Vc.
o.p.
Cb.


124
128
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
fl.t.
fl.t.
fl.t.
To Sop. Sax.
perhaps it is open
at the back


132
129
Fl.
raw
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
s.p.
raw
Cb.
s.p.
raw


136
134
Fl.
Cl.
Ten. Sax.
Soprano Saxophone
C Tpt.
Vib.
Mar.
Proj.Txt.
As thought grows dimmer,
grace emerges more brilliantly...
Pno.
Vc.
Cb.


142
139
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.


145
144
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
But grace itself returns when awareness has gone through an infinity.
Pno.
Vc.
s.p.
ord.
Cb.
s.p.
ord.


150
149
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
air only
(sounds ppp - p)
fl.t.


158
154
Fl.
Cl.
Sop. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
fl.t.
fl.t.
fl.t.


161
159
Fl.
Cl.
Sop. Sax.
To Ten. Sax.
senza sord.
C Tpt.
(senza sord.)
Vib.
To Perc.
Mar.
Proj.Txt.
Pno.
sul G
Vc.
sul A
Cb.


163
162
Fl.
ff
Cl.
To B. Cl.
fff
Sop. Sax.
C Tpt.
fff
fl.t.
quasi-gliss
mp
Percussion
spring coil
soft mallets
Perc.
pp
mp
l.v.
pp
Mar.
To Perc.
Percussion
bass drum
super-ball mallet
ppp
f
ppp
Proj.Txt.
Pno.
Vc.
fff
mp
Cb.
mp


166
Fl.
Cl.
Tenor Saxophone
Ten. Sax.
C Tpt.
Vibraphone
Vib.
Marimba
Mar.
Proj.Txt.
Pno.
Vc.
Cb.


170
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Grace appears most purely
in that form which either
has no consciousness...
Pno.
Vc.
Cb.
ppp
mf
f
mp

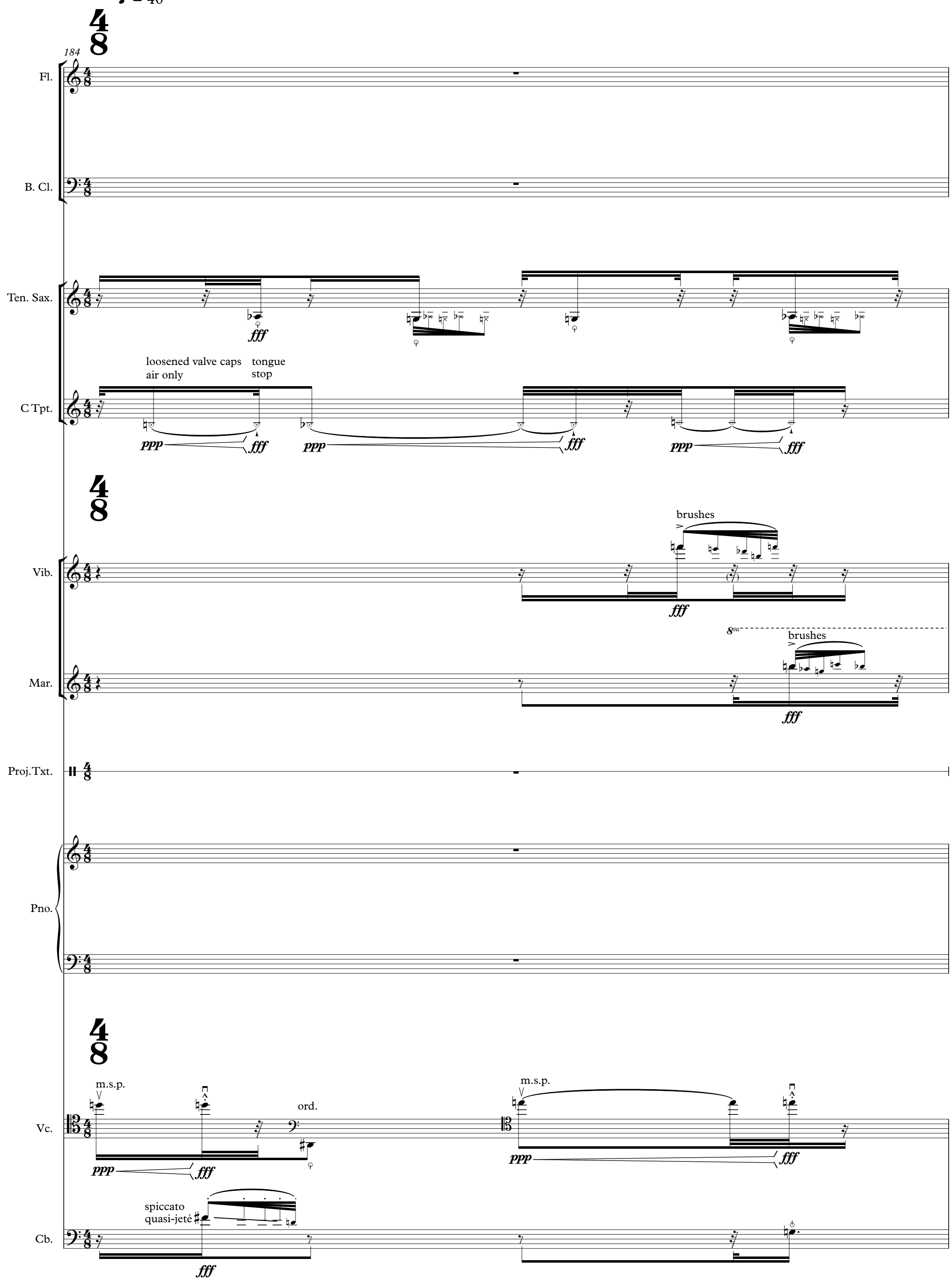

175
174
Fl.
Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
Bass Clarinet
in B♭
loosen valve caps slightly
will create clattering when
fingerings change
white key gliss
sul G
ord.

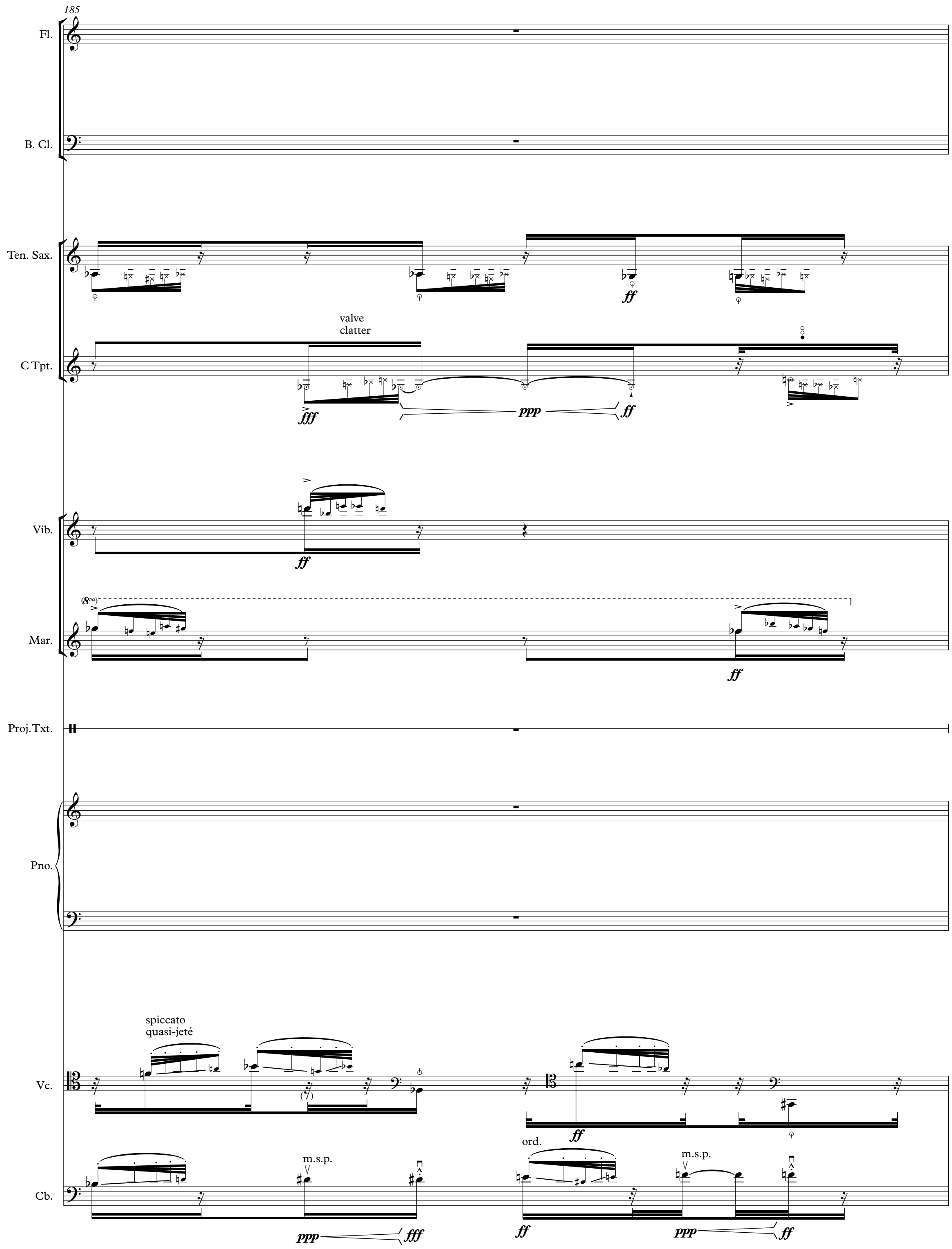

178
177
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
Pno.
Vc.
Cb.
o.p.
ord.
o.p.
ord.
sul A
ord.
o.p.
ord.
o.p.


182
181
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
Mar.
Proj.Txt.
...or an infinte consciousness.
Pno.
Vc.
Cb.
ord.
o.p.
pp
mp
ppp
p
mf

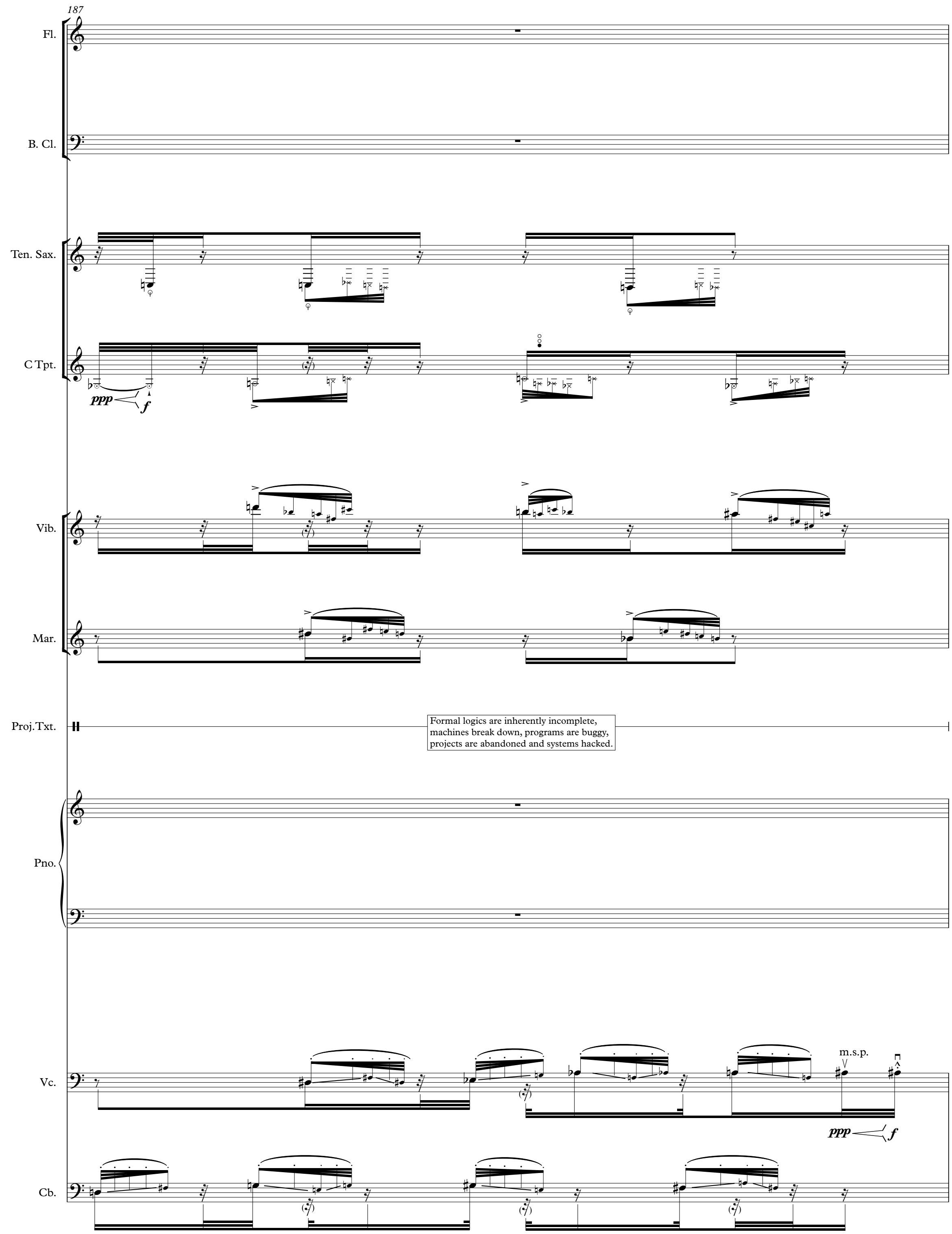
184 **III. b. UNINTENDED CONSEQUENCES**

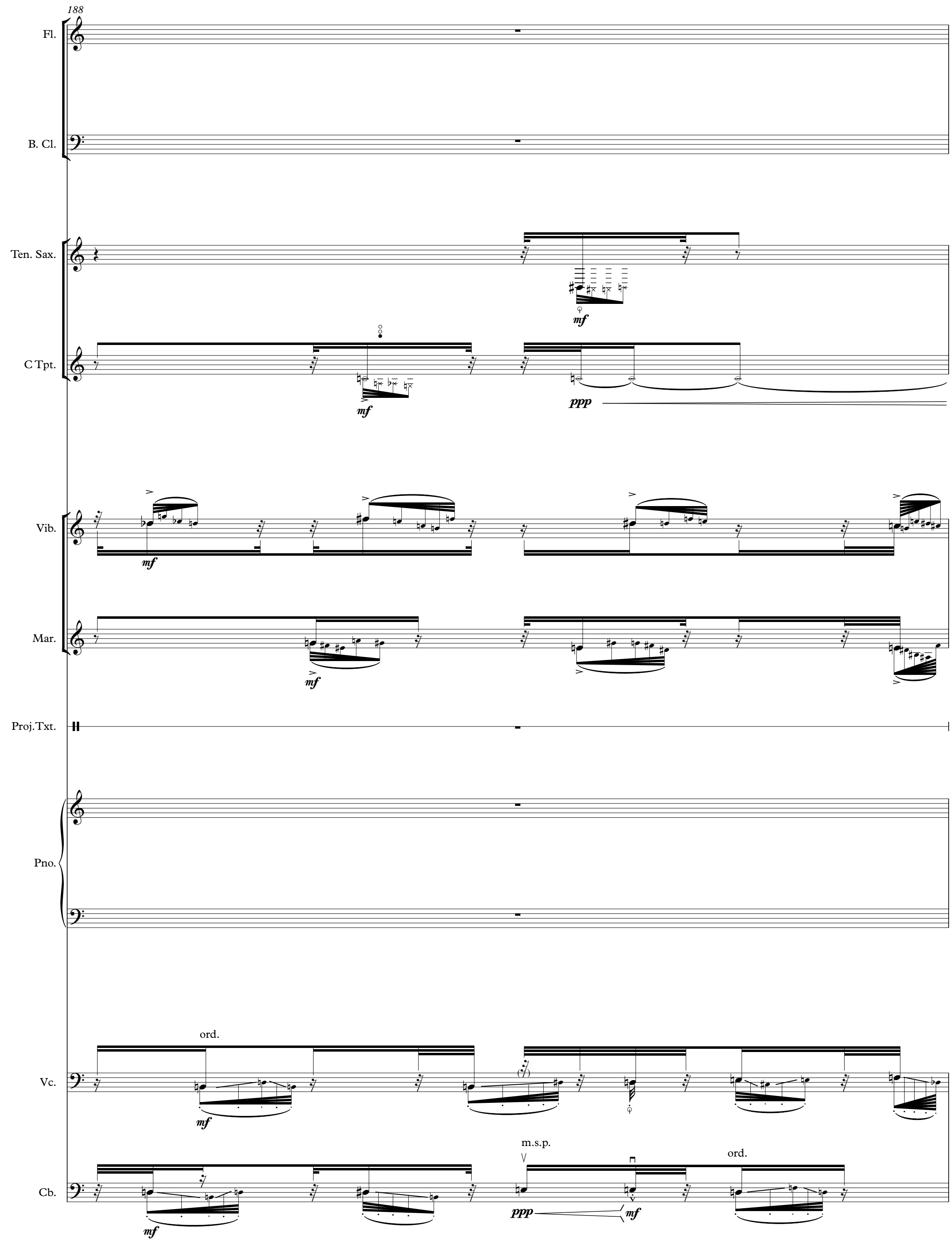
♪ = 40

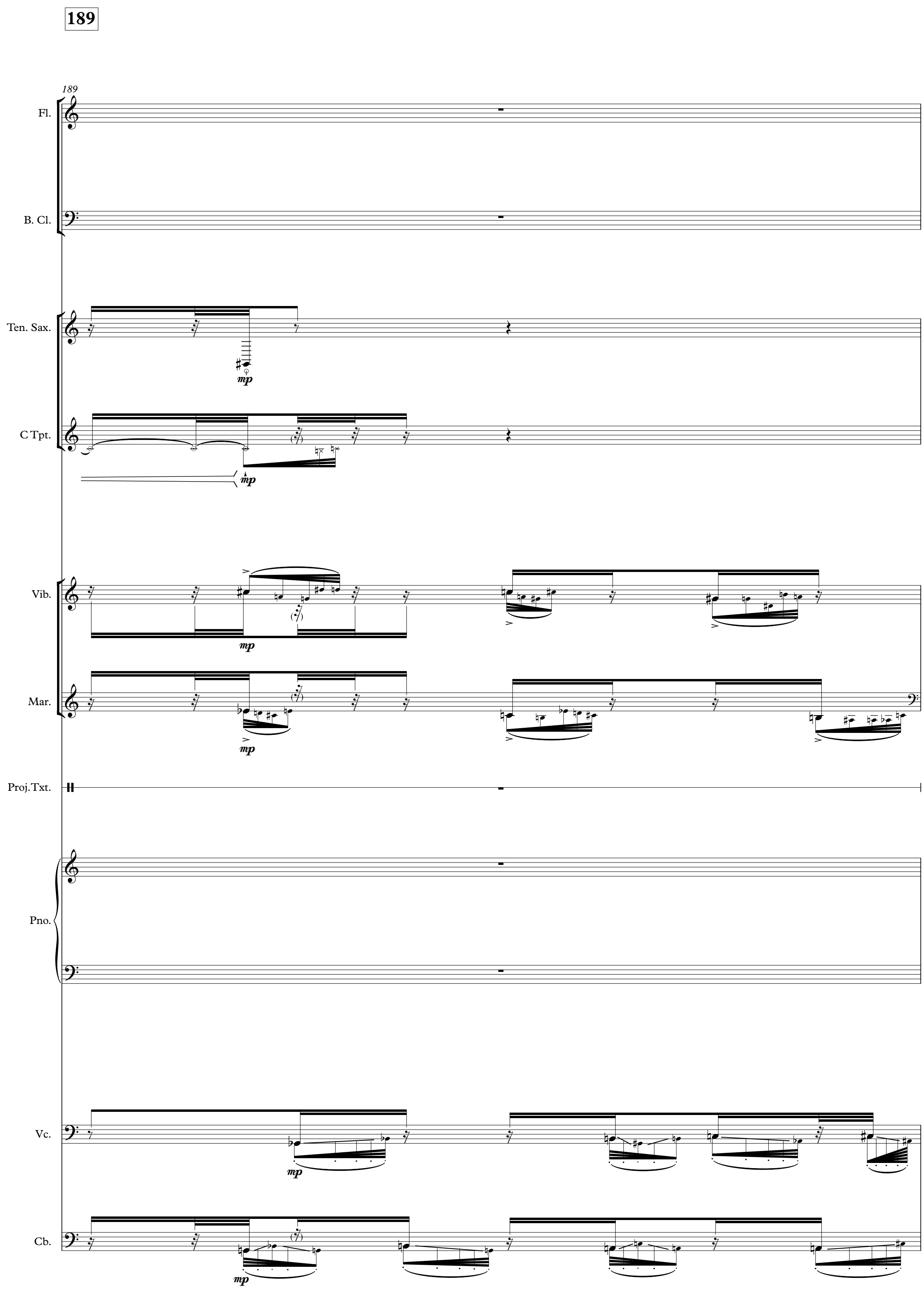


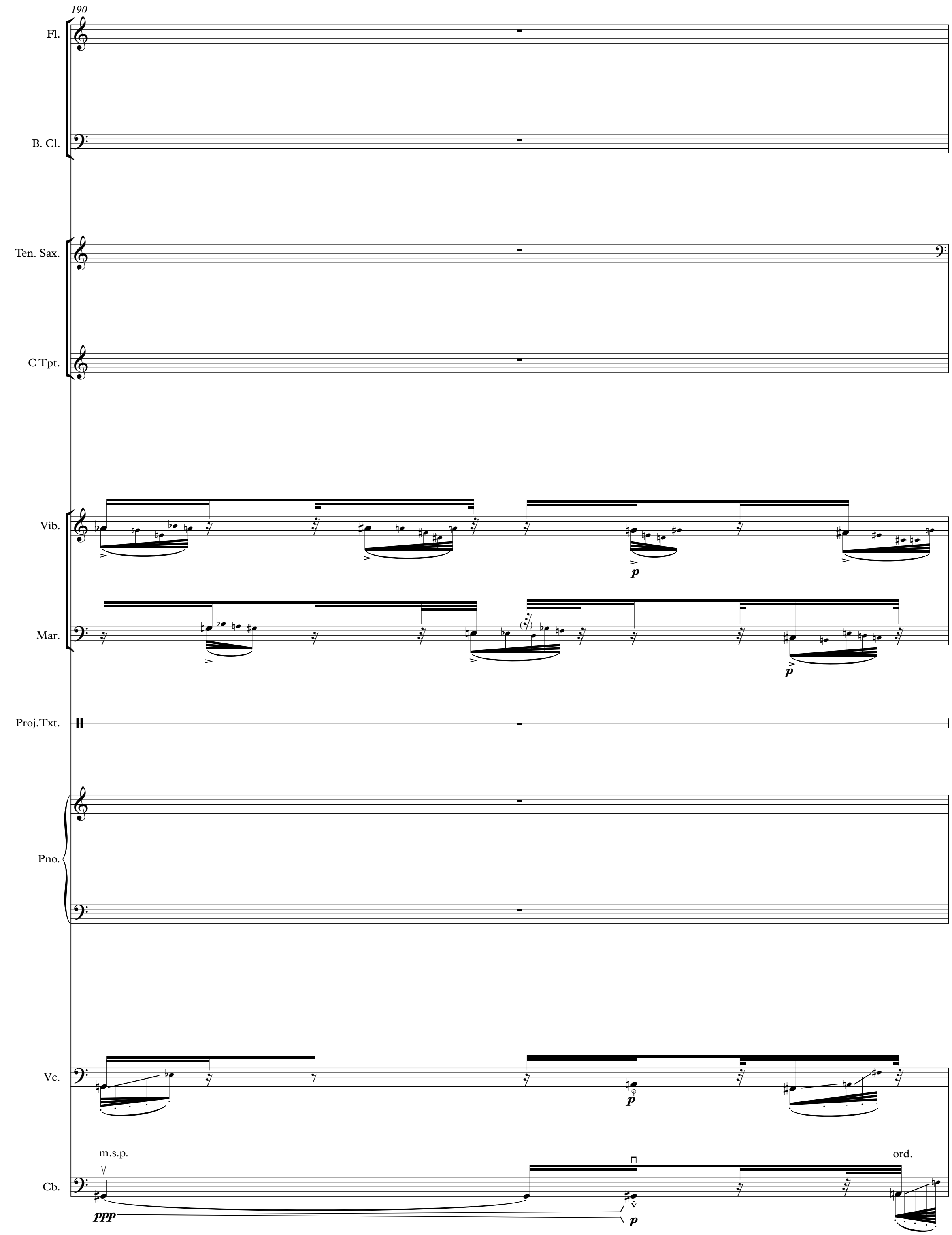

185
Fl.
B. Cl.
Ten. Sax.
ff
valve
clatter
C Tpt.
fff
ppp
ff
Vib.
ff
Mar.
ff
Proj.Txt.
Pno.
spiccato
quasi-jeté
Vc.
ff
ord.
m.s.p.
m.s.p.
Cb.
ppp
fff
ff
ppp
ff

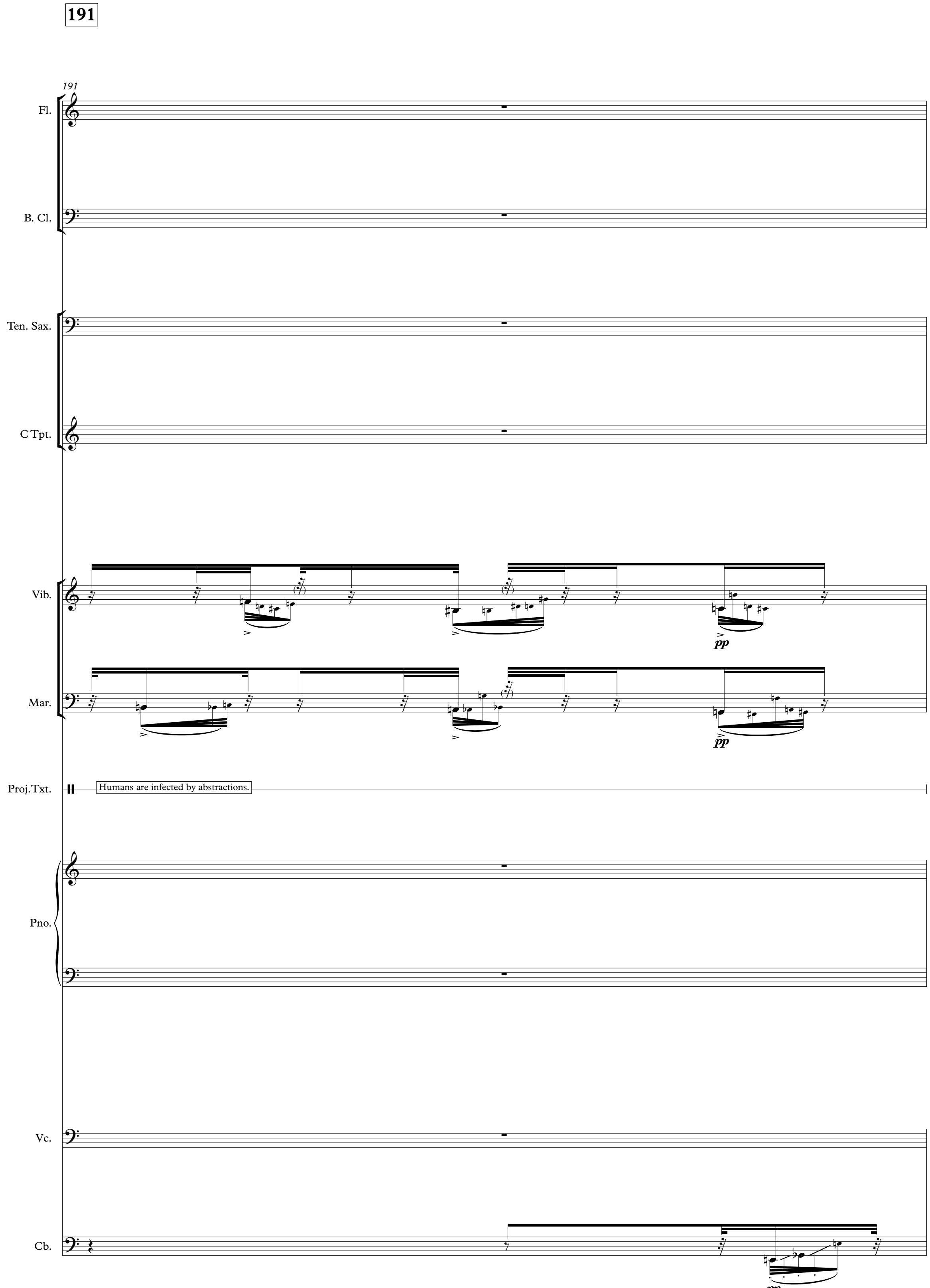

186
186
Fl.
B. Cl.
Ten. Sax.
f
C Tpt.
ppp
f
Vib.
f
Mar.
f
Proj.Txt.
Pno.
Vc.
m.s.p.
ord.
ppp
f
Cb.
ord.
f

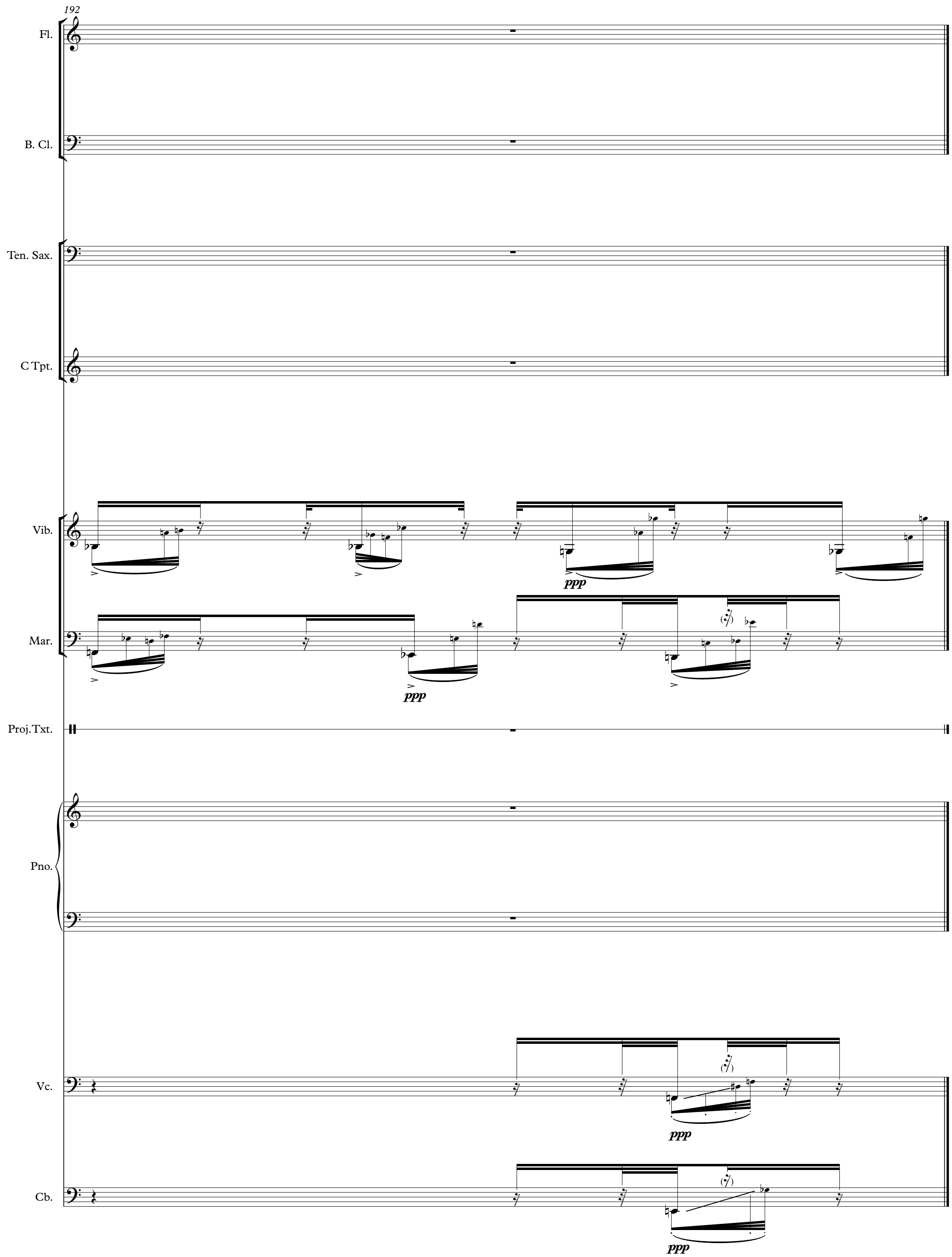

187
Fl.
B. Cl.
Ten. Sax.
C Tpt.
ppp
f
Vib.
Mar.
Proj.Txt.
Formal logics are inherently incomplete, machines break down, programs are buggy, projects are abandoned and systems hacked.
Pno.
Vc.
m.s.p.
ppp
f
Cb.


188
Fl.
B. Cl.
Ten. Sax.
mf
C Tpt.
mf
ppp
Vib.
mf
Mar.
mf
Proj.Txt.
Pno.
ord.
Vc.
mf
m.s.p.
ord.
Cb.
mf
ppp
mf


189
189
Fl.
B. Cl.
Ten. Sax.
mp
C Tpt.
mp
Vib.
mp
Mar.
mp
Proj.Txt.
Pno.
Vc.
mp
Cb.
mp


190
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
p
Mar.
p
Proj.Txt.
Pno.
Vc.
p
m.s.p.
ord.
Cb.
ppp
p


191
191
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
pp
Mar.
pp
Proj.Txt.
Humans are infected by abstractions.
Pno.
Vc.
Cb.
pp


192
Fl.
B. Cl.
Ten. Sax.
C Tpt.
Vib.
ppp
Mar.
ppp
Proj.Txt.
Pno.
Vc.
ppp
Cb.
ppp

APPENDIX: Representative MAX patches for *Apocryphal Chrysopoeia*

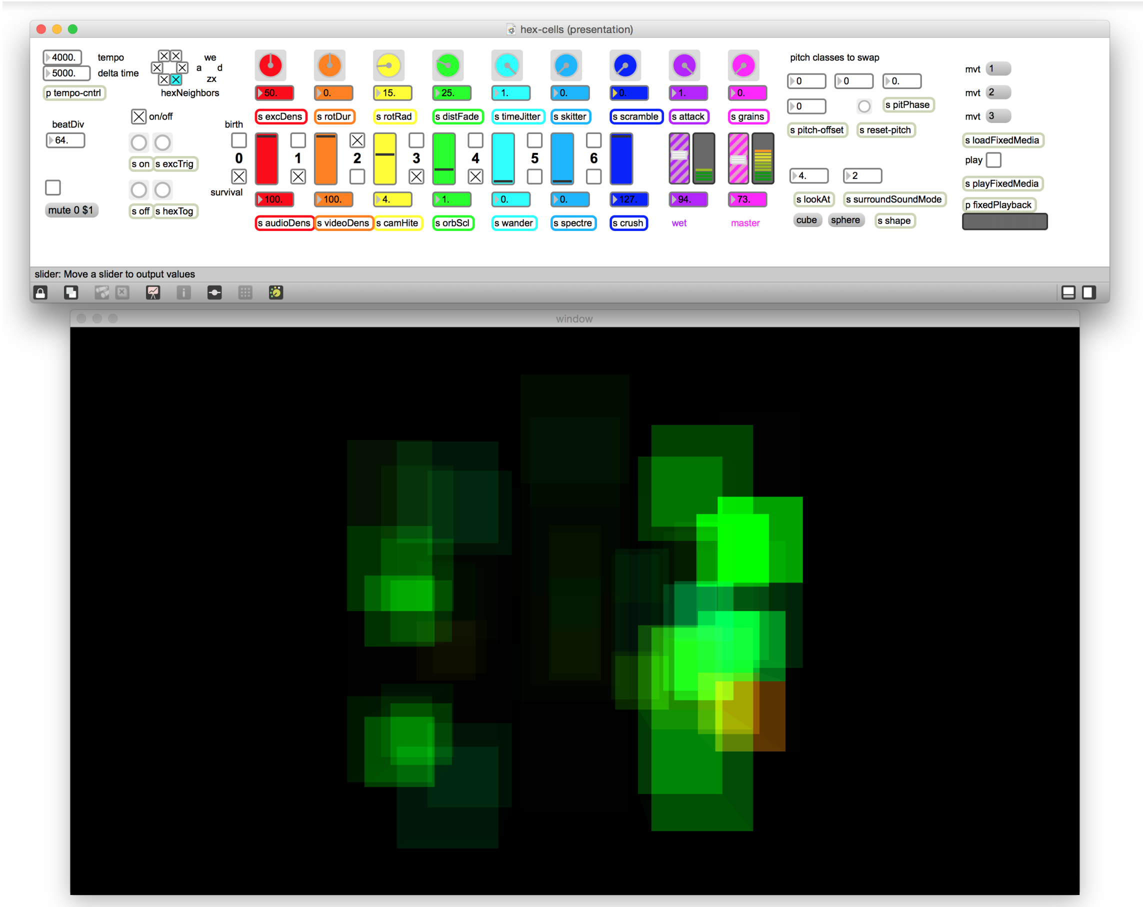


Figure 39. hex-cells: Top-level patch in presentation mode for performance, with rendering window below.

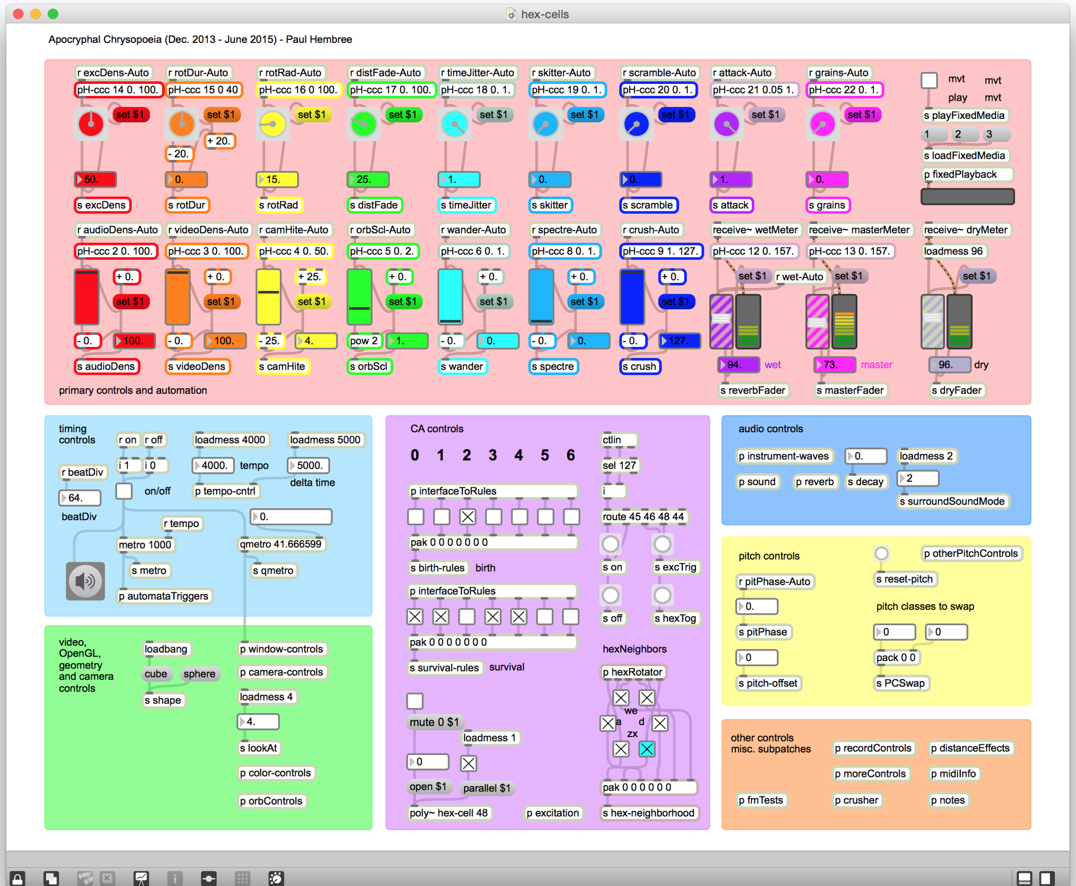


Figure 40. hex-cells: Top-level patch in editing mode.

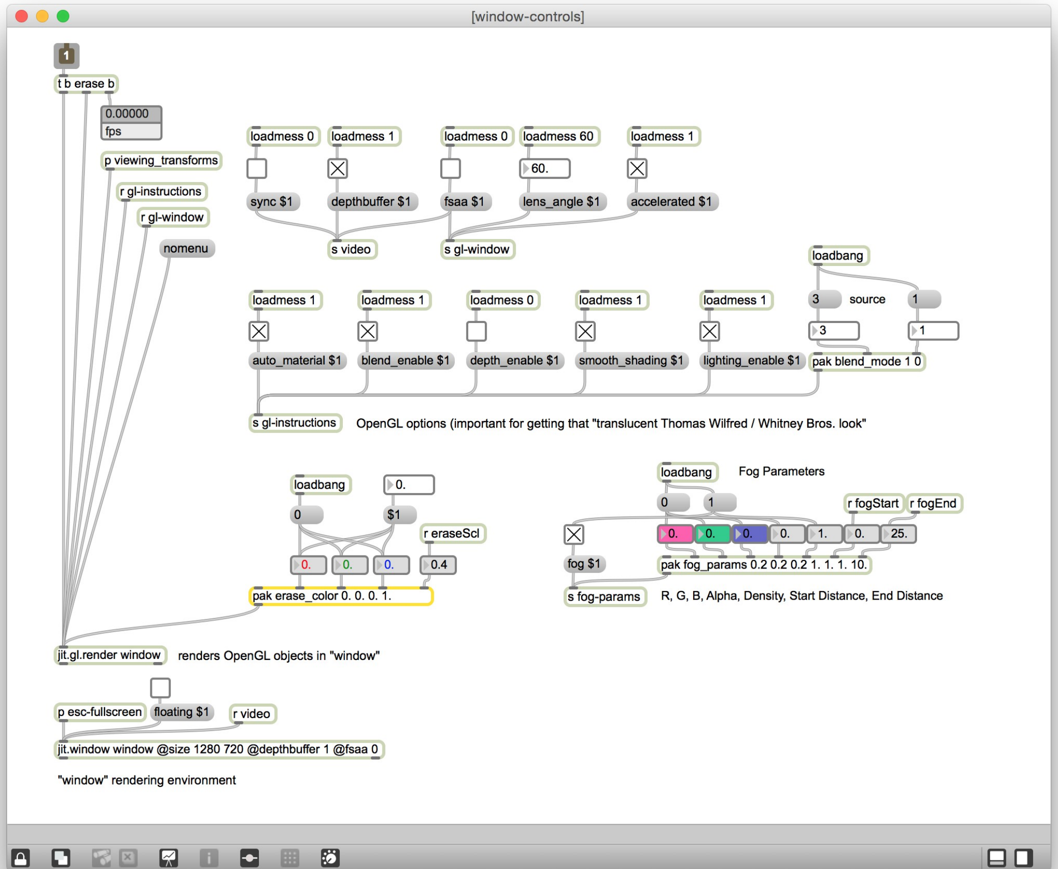


Figure 41. window-controls (sub-patch of hex-cells): Various OpenGL blend mode options, OpenGL rendering environment object, and floating window object.

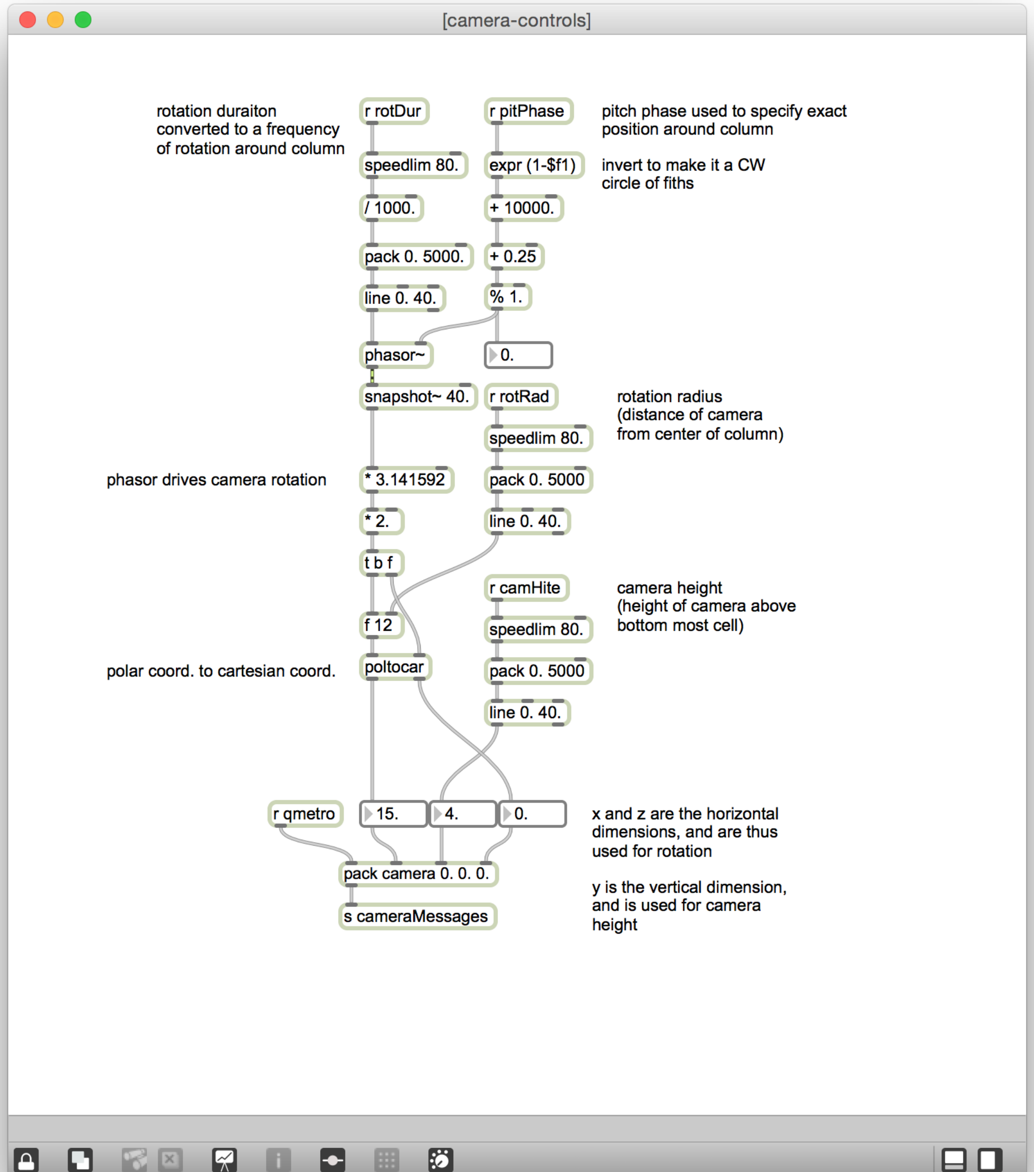


Figure 42. camera-controls (sub-patch of hex-cells): Four different variables control how the camera position changes over time.

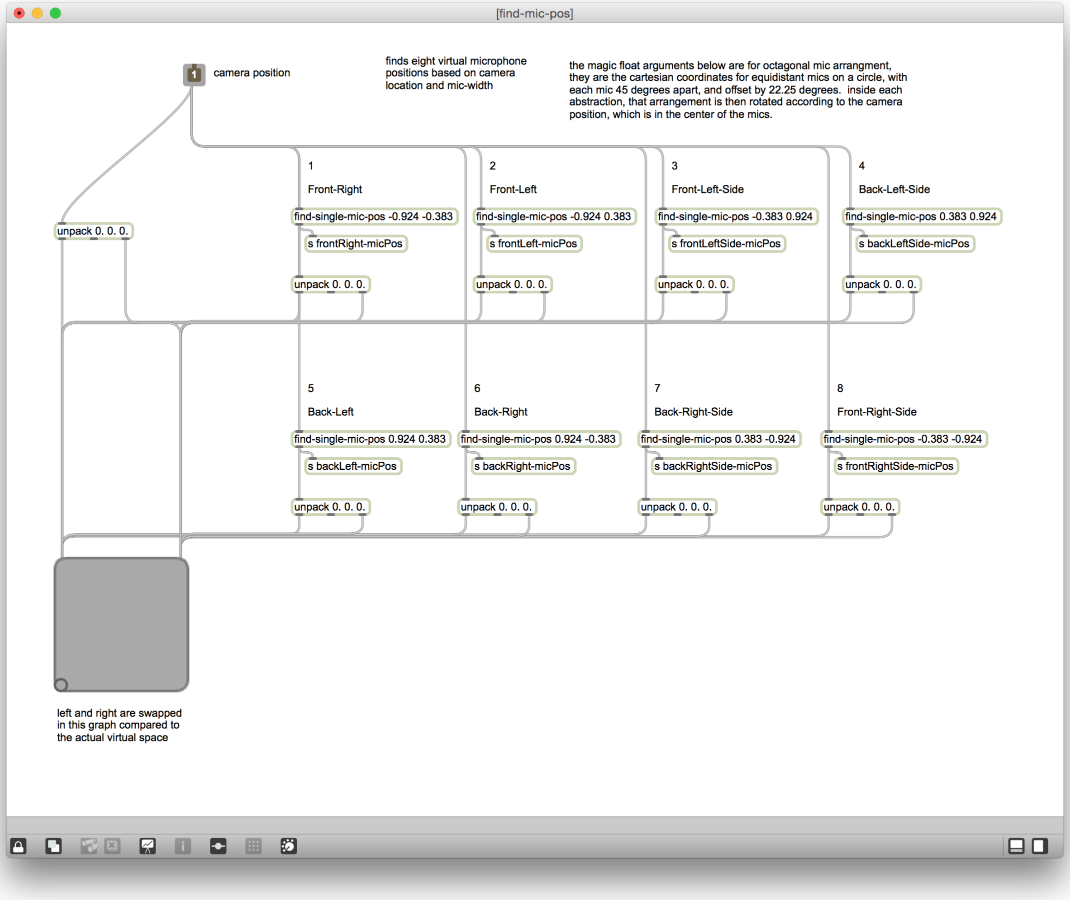


Figure 43. find-mic-pos (sub-patch of window-controls): Calculates position of all virtual microphones based on camera position.

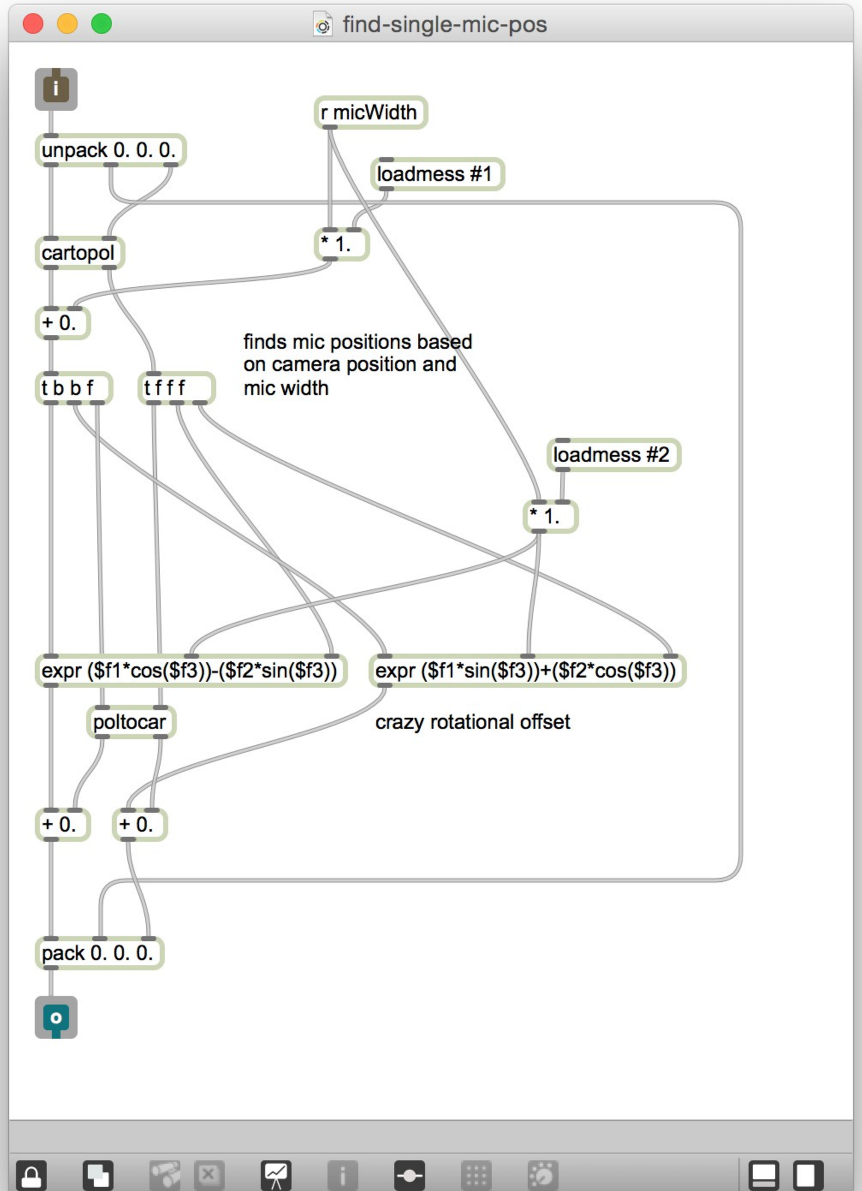


Figure 44. find-single-mic-pos (sub-patch of find-mic-pos): Calculates an individual virtual microphone position.

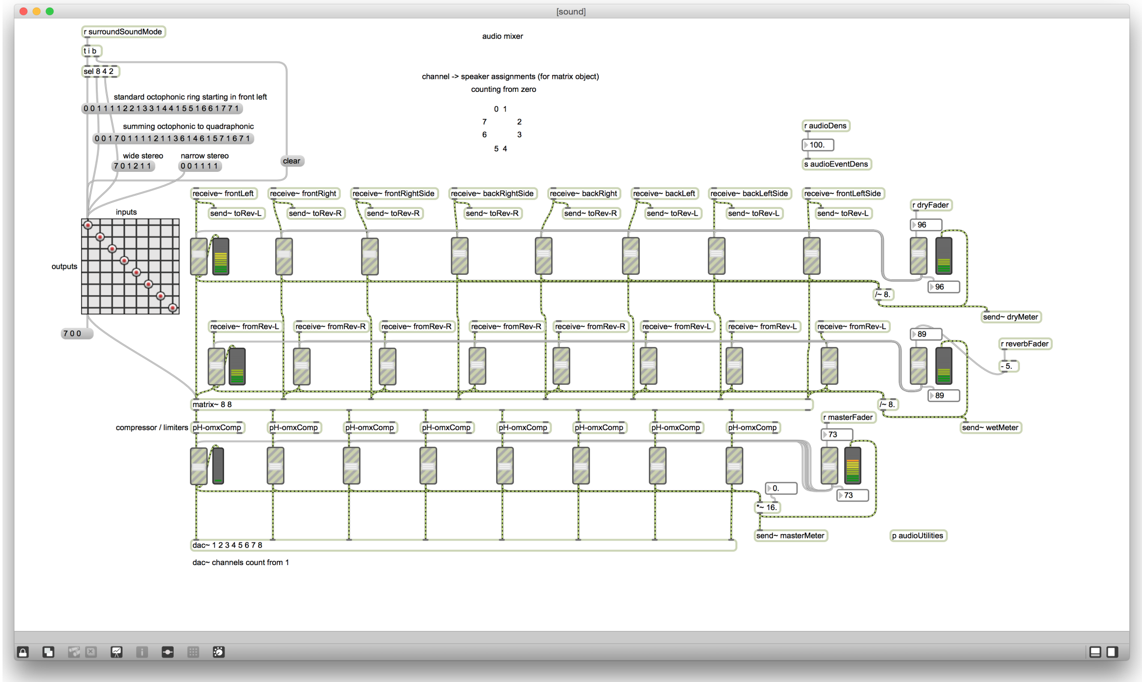


Figure 45. sound (sub-patch of hex-cells): Audio mixer receives signals from all sound modules, routes to a global stereo reverb, and passes signals to the digital-to-analog converter.

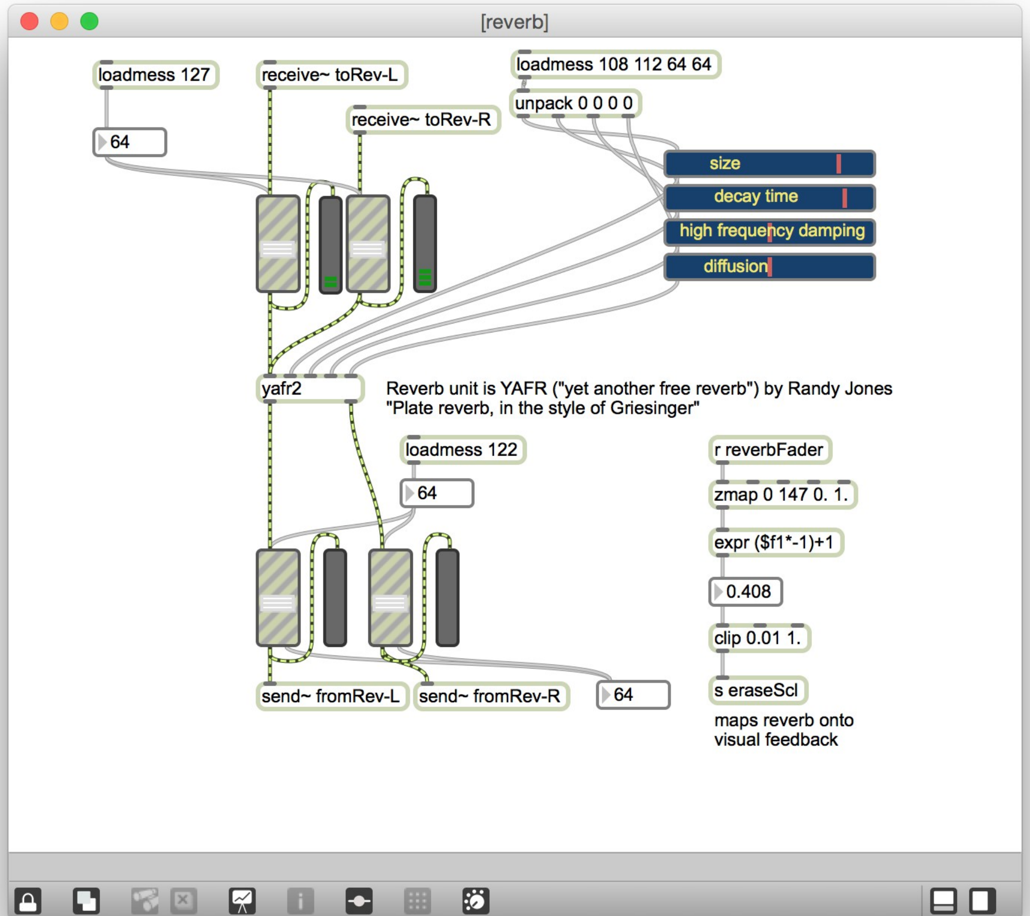


Figure 46. reverb (sub-patch of hex-cells): Global stereo reverb and visual feedback mapping.

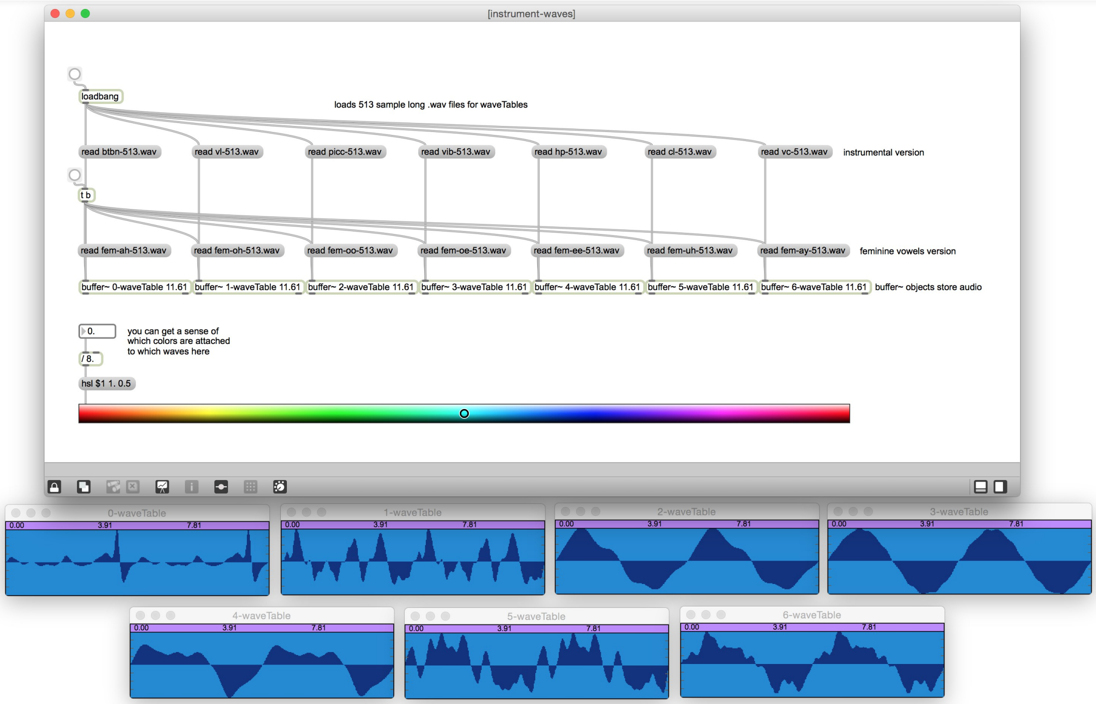


Figure 47. instrument-waves (sub-patch of hex-cells): Audio buffers hold two periods of waveforms borrowed from several acoustic instruments.

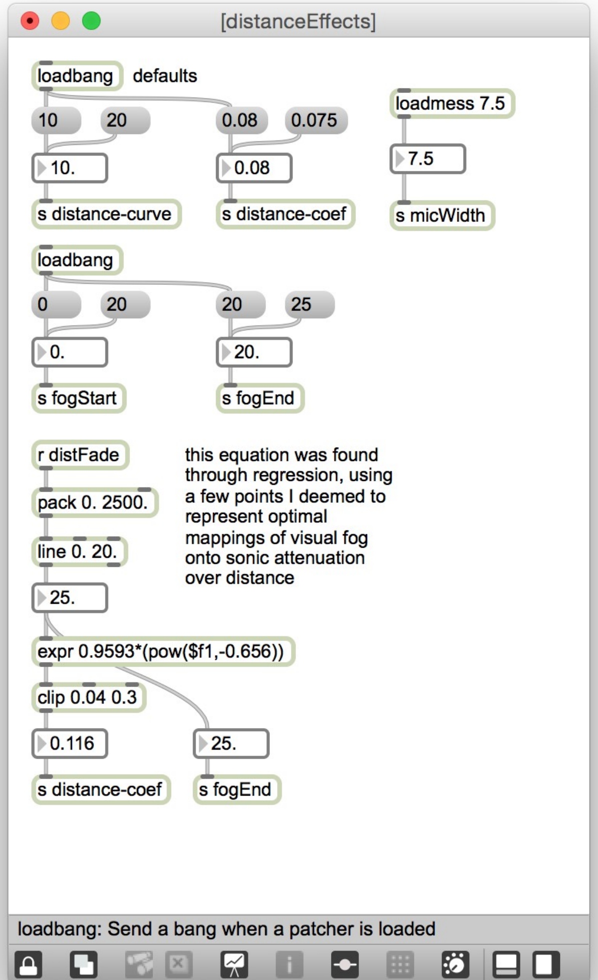


Figure 48. distanceEffects (sub-patch of hex-cells): Contains an equation to map the application of fog to the geometric primitives onto the sonic attenuation over distance.

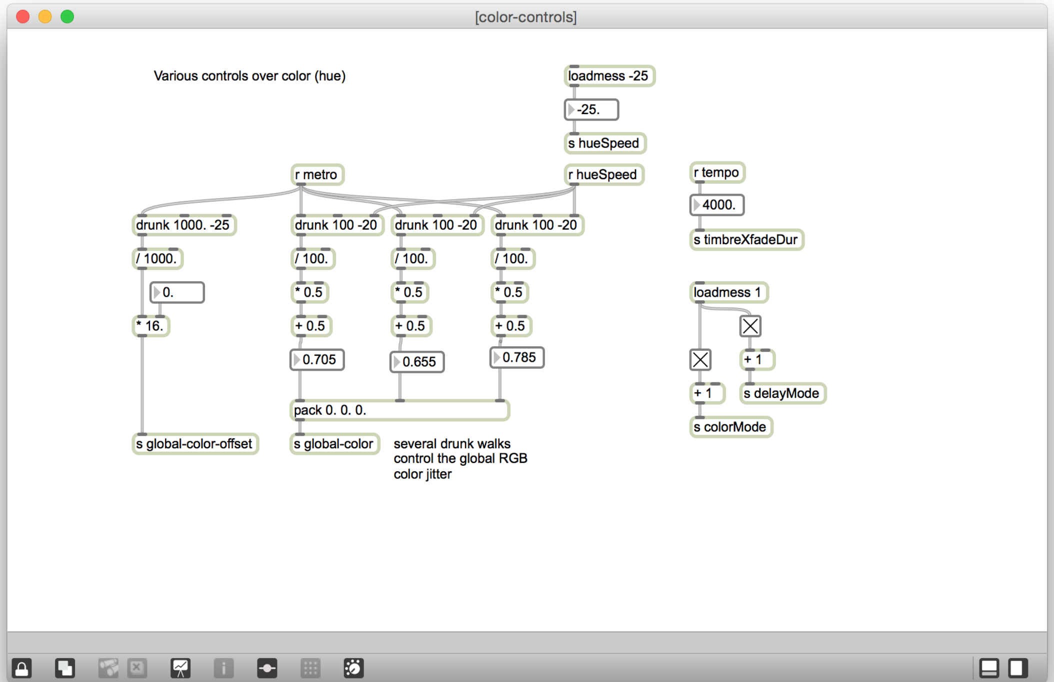


Figure 49. color-controls (sub-patch of hex-cells): Color, in RGB values, is modulated continuously by several random walks.

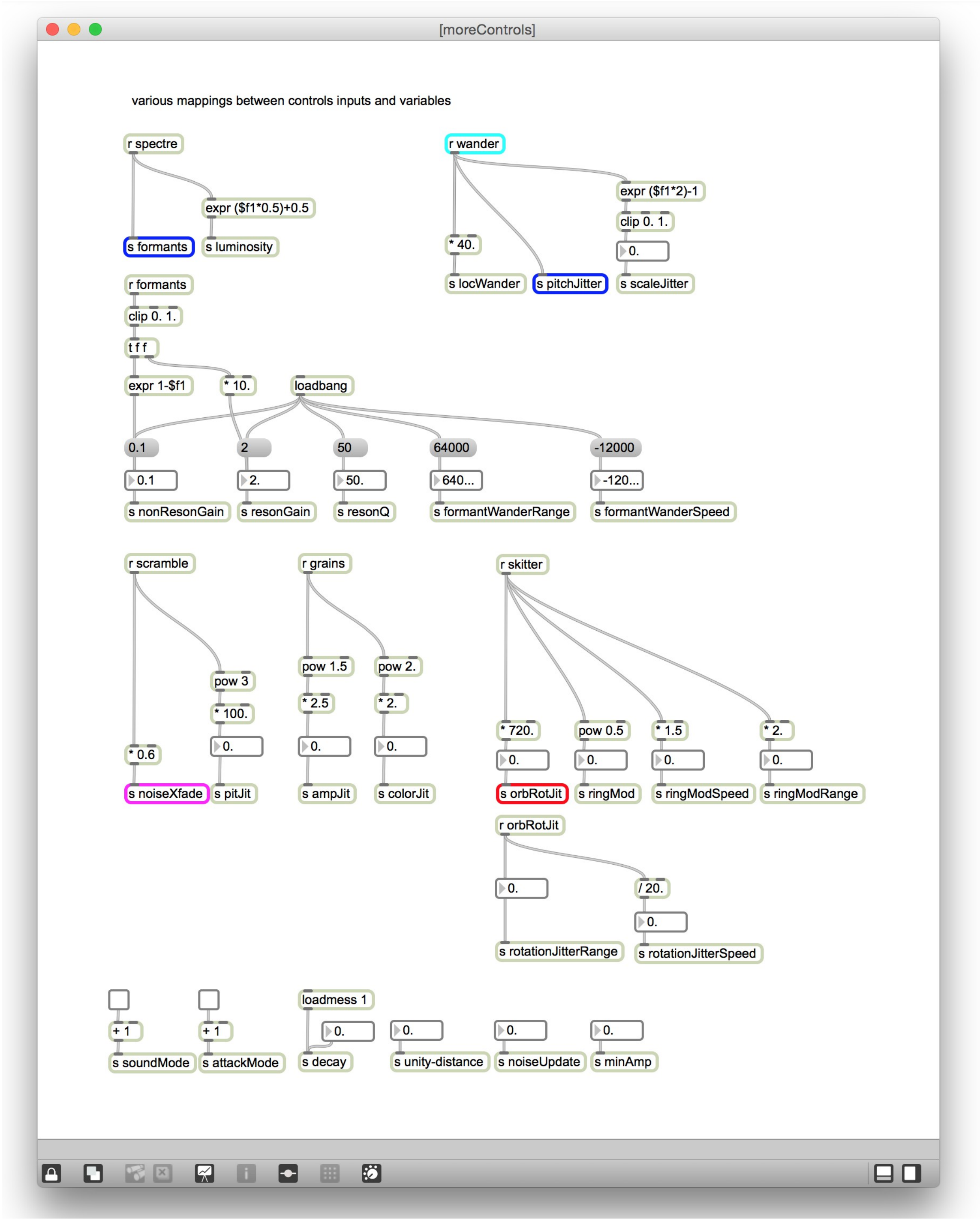


Figure 50. moreControls (sub-patch of hex-cells): This patch contains several mappings of global control variables onto specific sub-variables responsible for audio-visual effects.

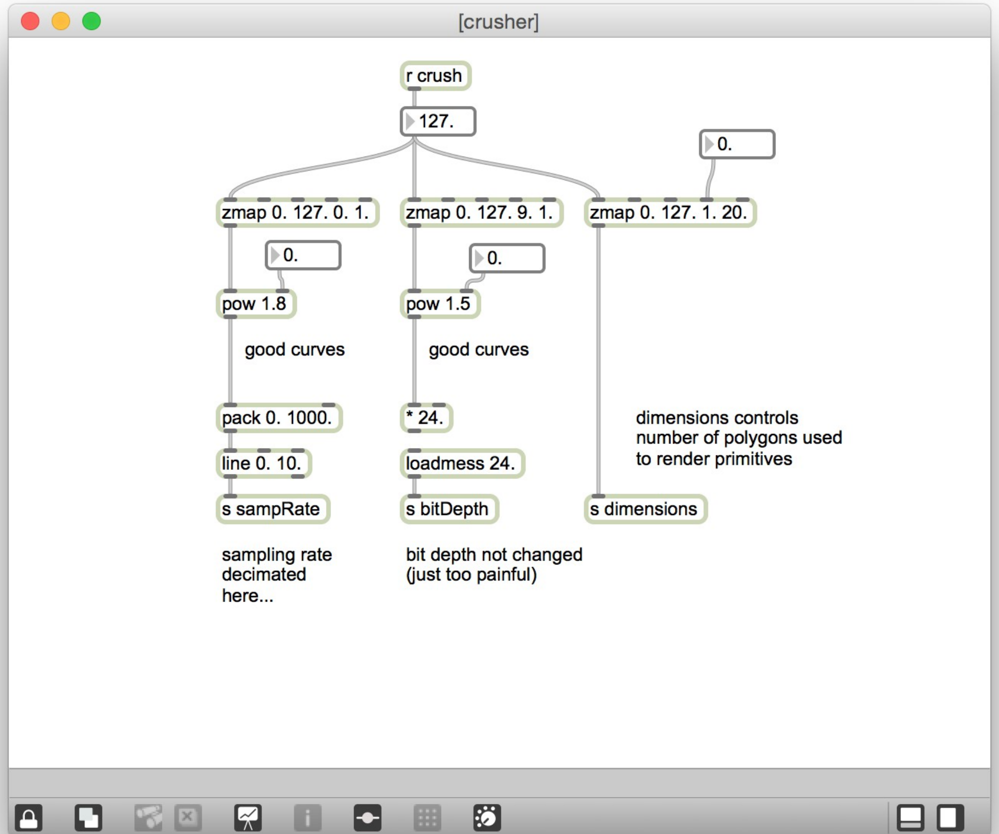


Figure 51. crusher (sub-patch of hex-cells): Routes and maps global *crush* variable onto sampling rate decimation and polygon count.

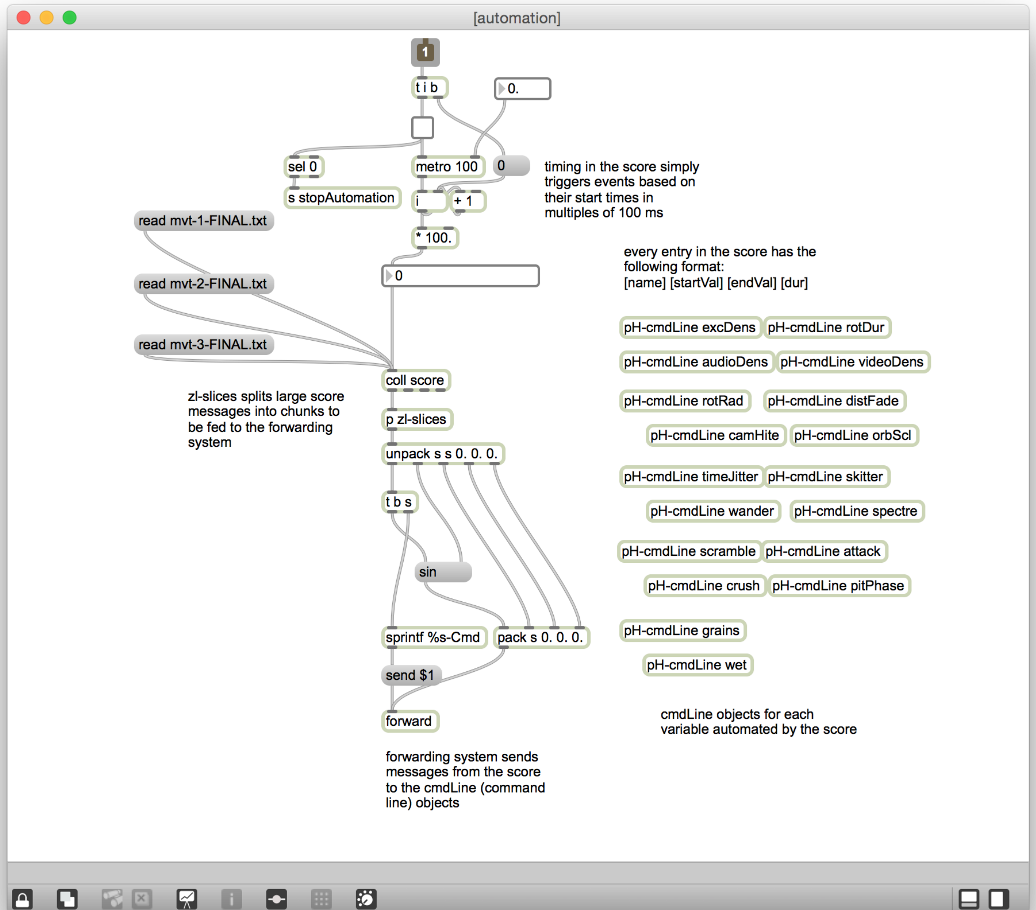


Figure 52. automation (sub-patch of hex-cells): Automation of global variables can be controlled with score files, stored in the coll object. Messages from the score file are routed to specific pH-cmdLine (command line) objects assigned to control those global variables.

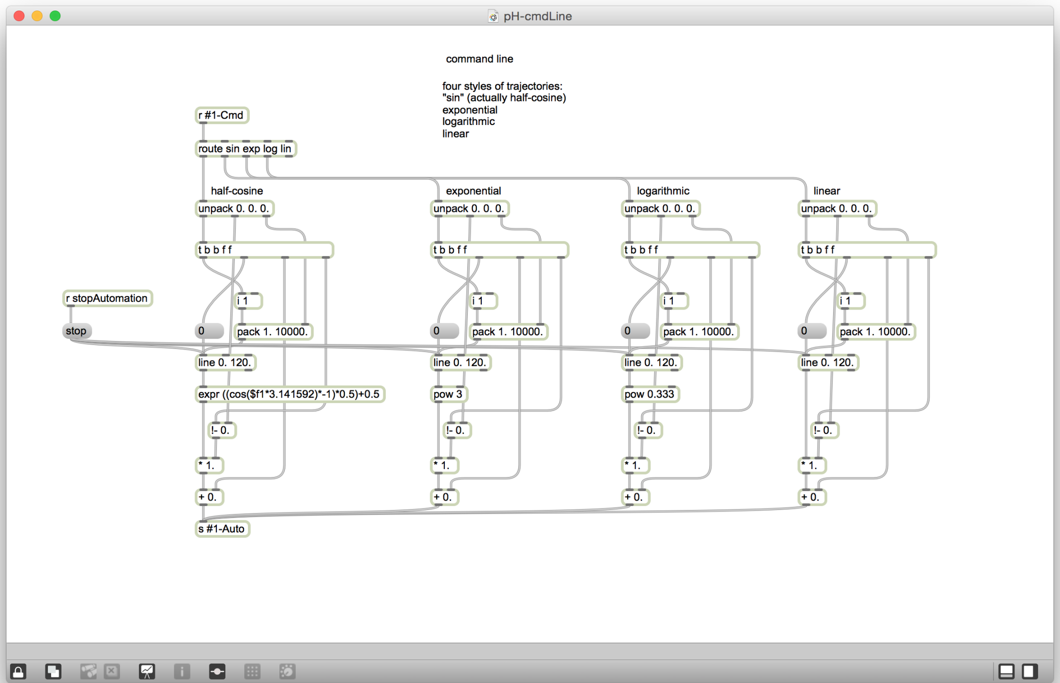


Figure 53. pH-cmdLine (abstraction used in automation): This abstraction takes messages from the score and continuously outputs a control envelope, with a trajectory style, for a specific global variable.

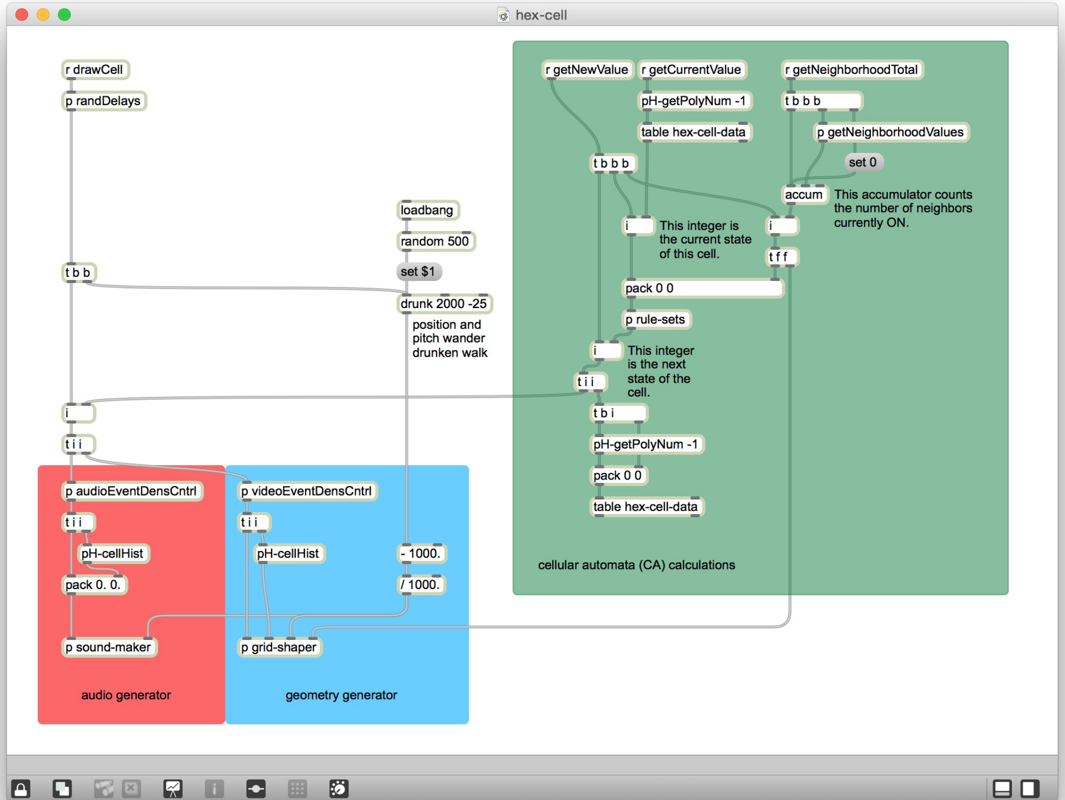


Figure 54. hex-cell (abstraction loaded in poly~): This abstraction is instantiated forty-eight times in the top-level patch. Each of these forty-eight hex-cells renders a geometric primitive and produces sound at a specific pitch. These can be thought of as the voices of a polyphonic synthesizer.

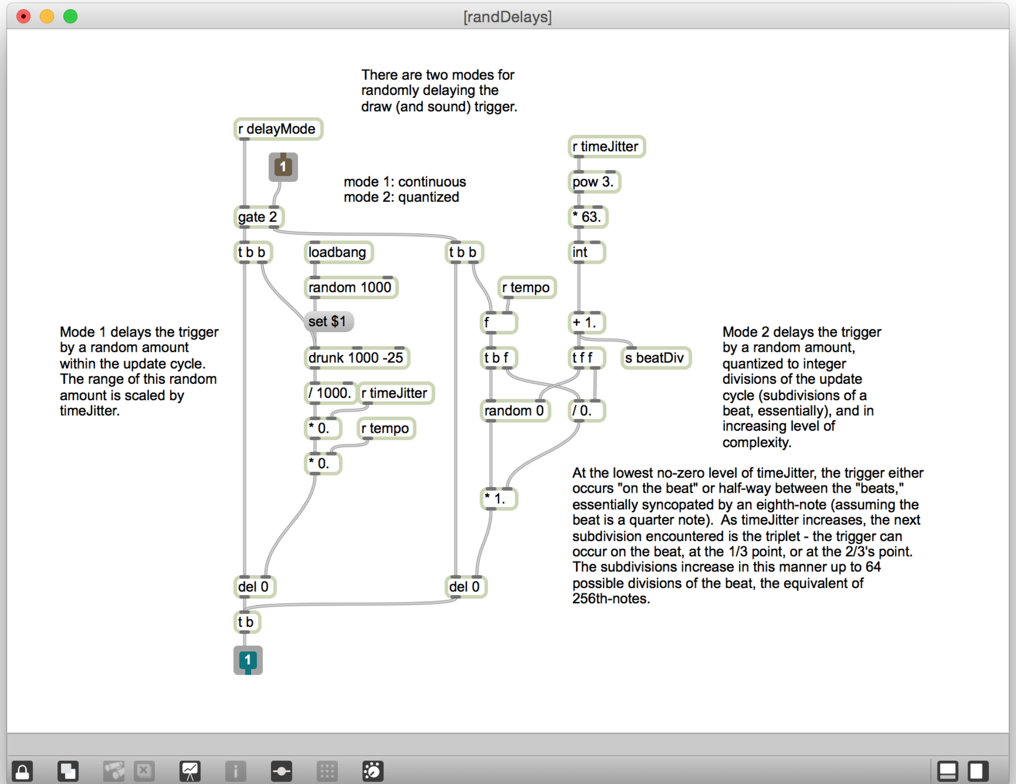


Figure 55. randDelays (sub-patch as hex-cell): Time jitter is produced in this sub-patch.

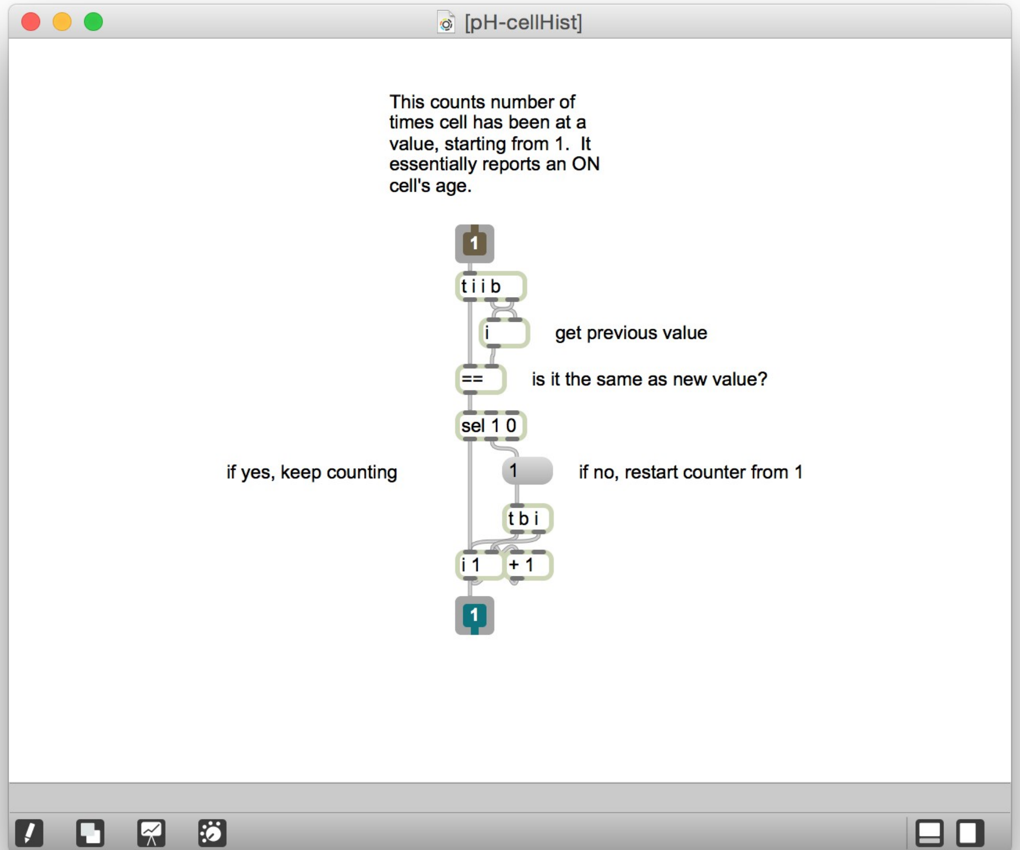


Figure 56. pH-cellHist (abstraction used in hex-cell): Counts the number of time-steps a cell has been active.

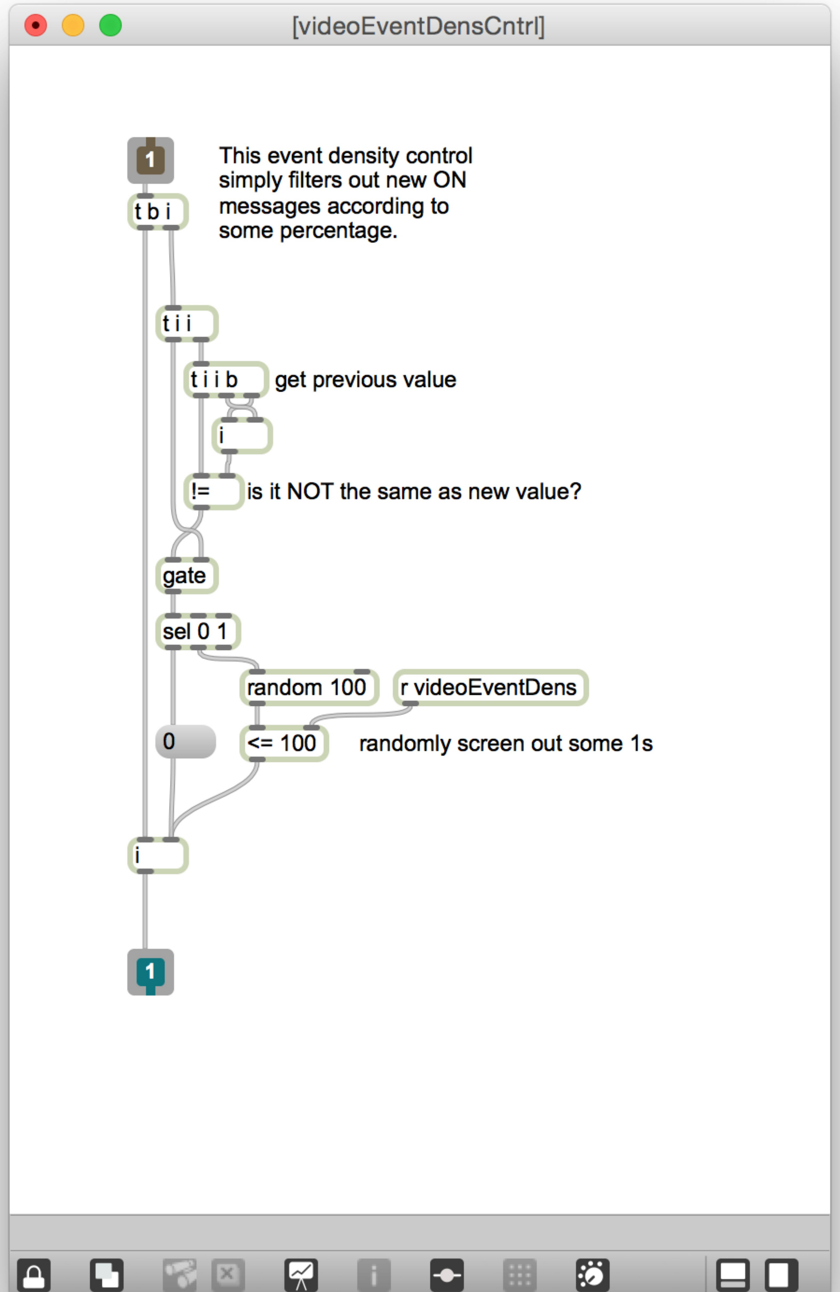


Figure 57. videoEventDensCntrl (subpatch of hex-cell): This patch, and an identical one for audio events, screens out activation messages according to a percentage.

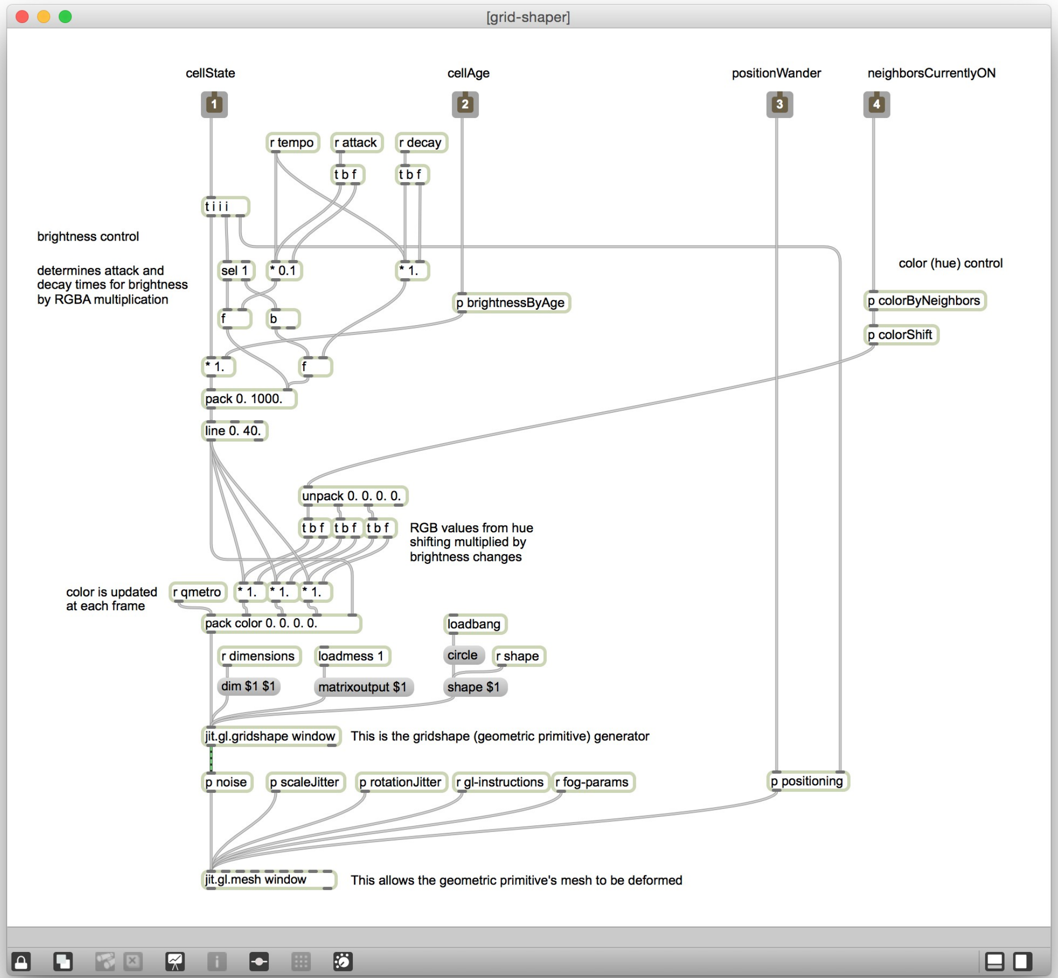


Figure 58. grid-shaper (sub-patch of hex-cell): Controls the positioning, coloring and activation of a translucent geometric primitive (a grid shape).

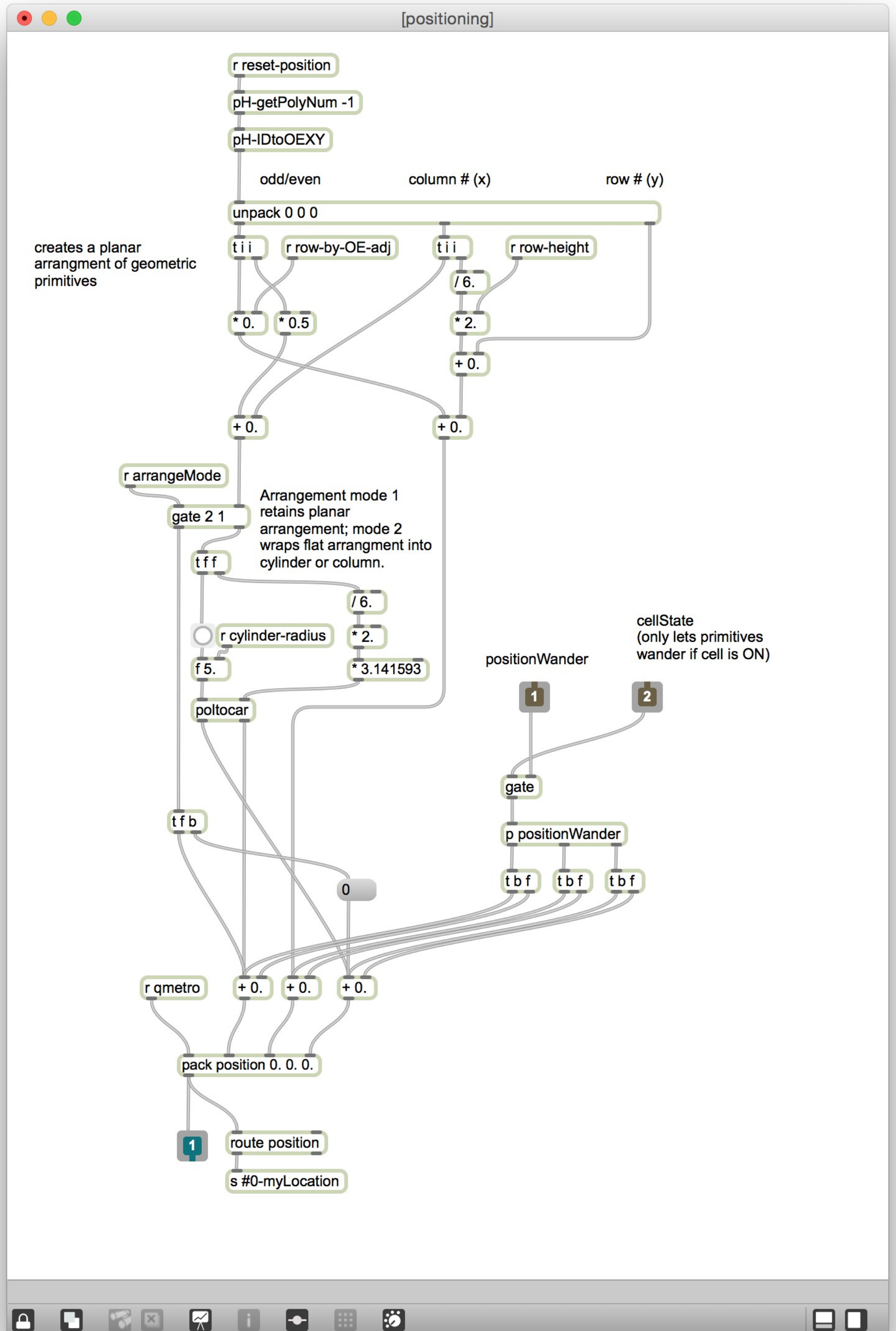


Figure 59. positioning (sub-patch of grid-shaper): Controls the initial position and deviation of that position for a hex-cell primitive.

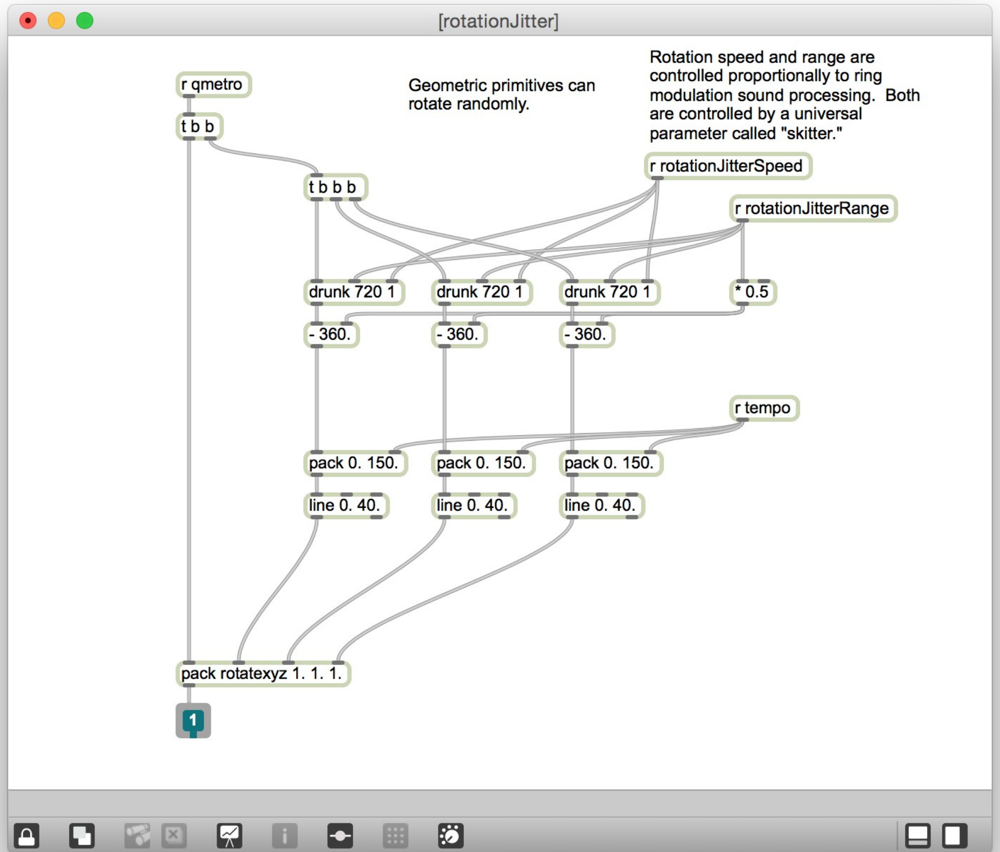


Figure 60. rotationJitter (sub-patch of grid-shaper): Random walks control the rotation of each individual primitive around its center point.

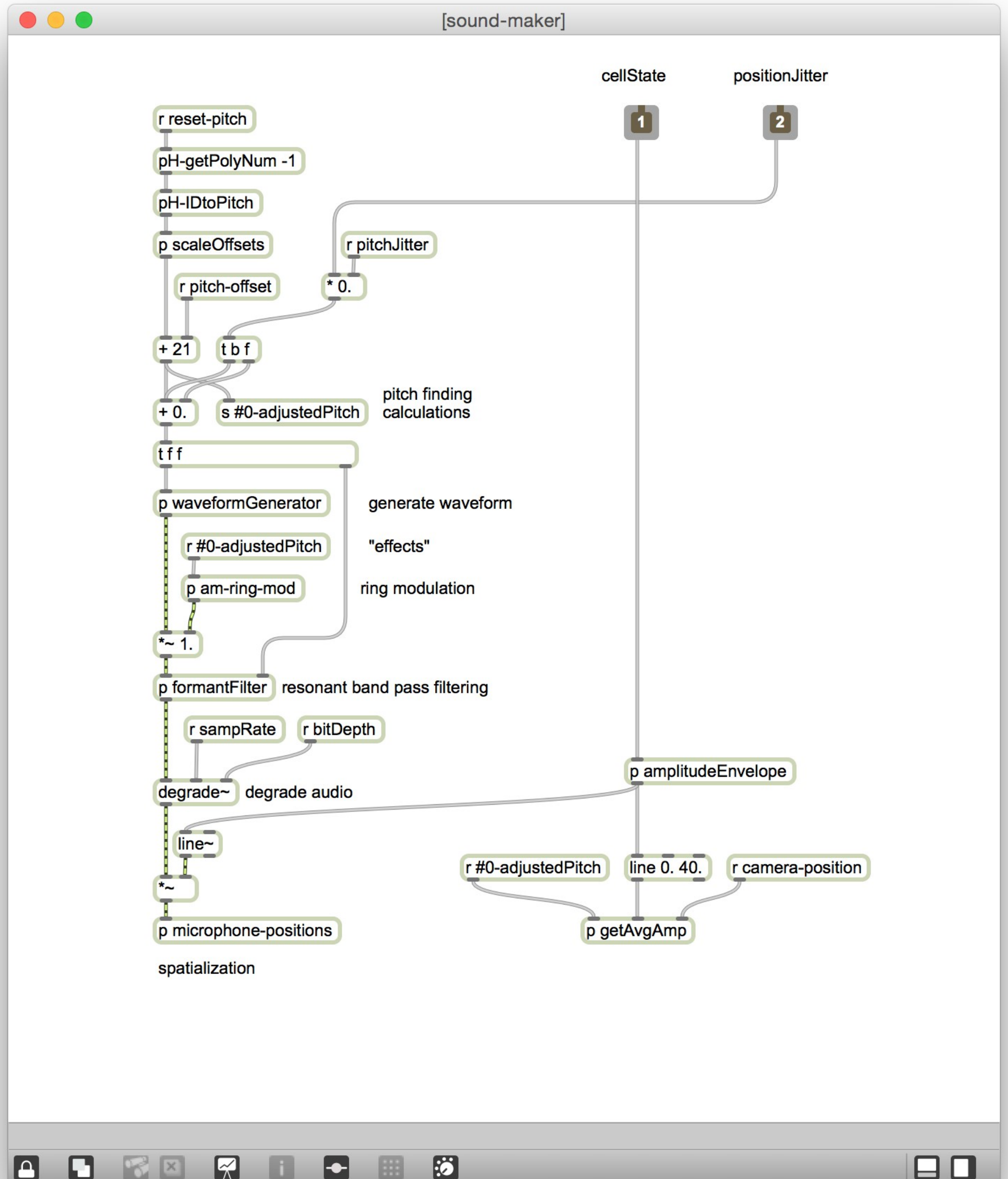


Figure 61. sound-maker (sub-patch of hex-cell): The audio signal for a hex-cell voice is generated, effected and sent to virtual microphones here.

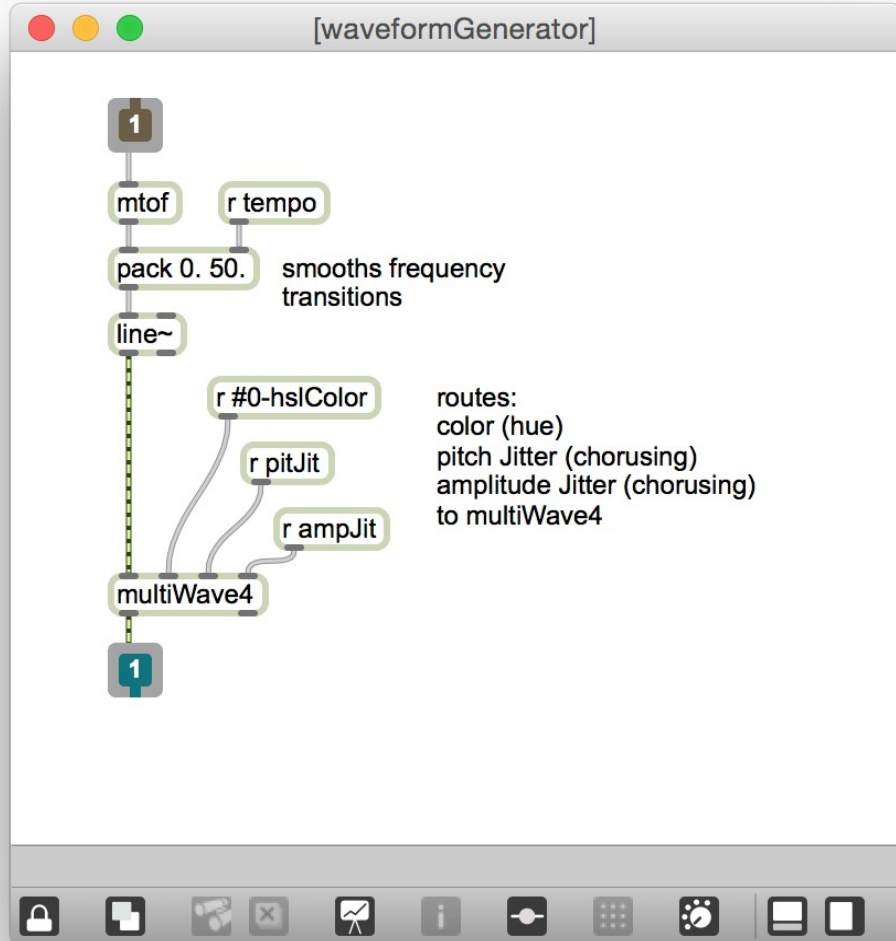


Figure 62. waveformGenerator (sub-patch of sound-maker): Routes several variables to the multi-timbral wavetable synthesizer, in addition to smoothing frequency transitions.

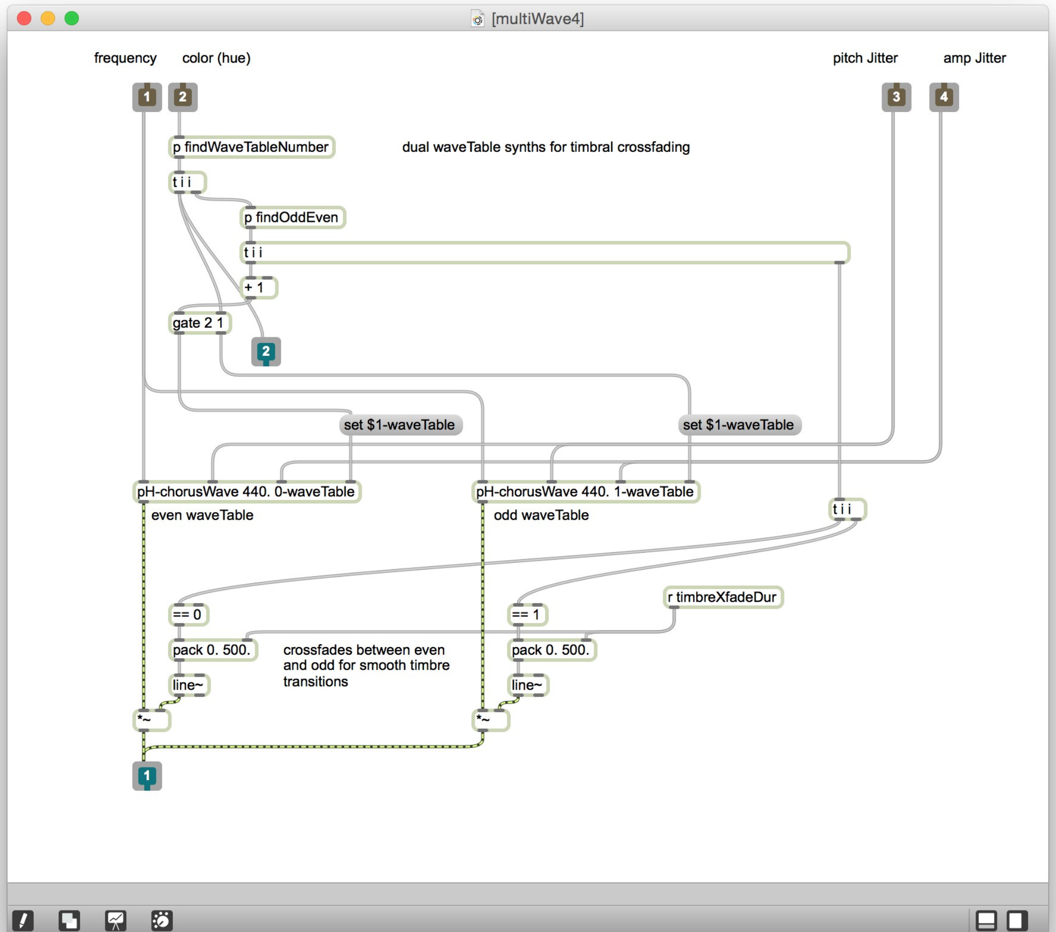


Figure 63. multiWave4 (abstraction within waveformGenerator): Dual wavetable synthesizer smoothly transitions between timbres.

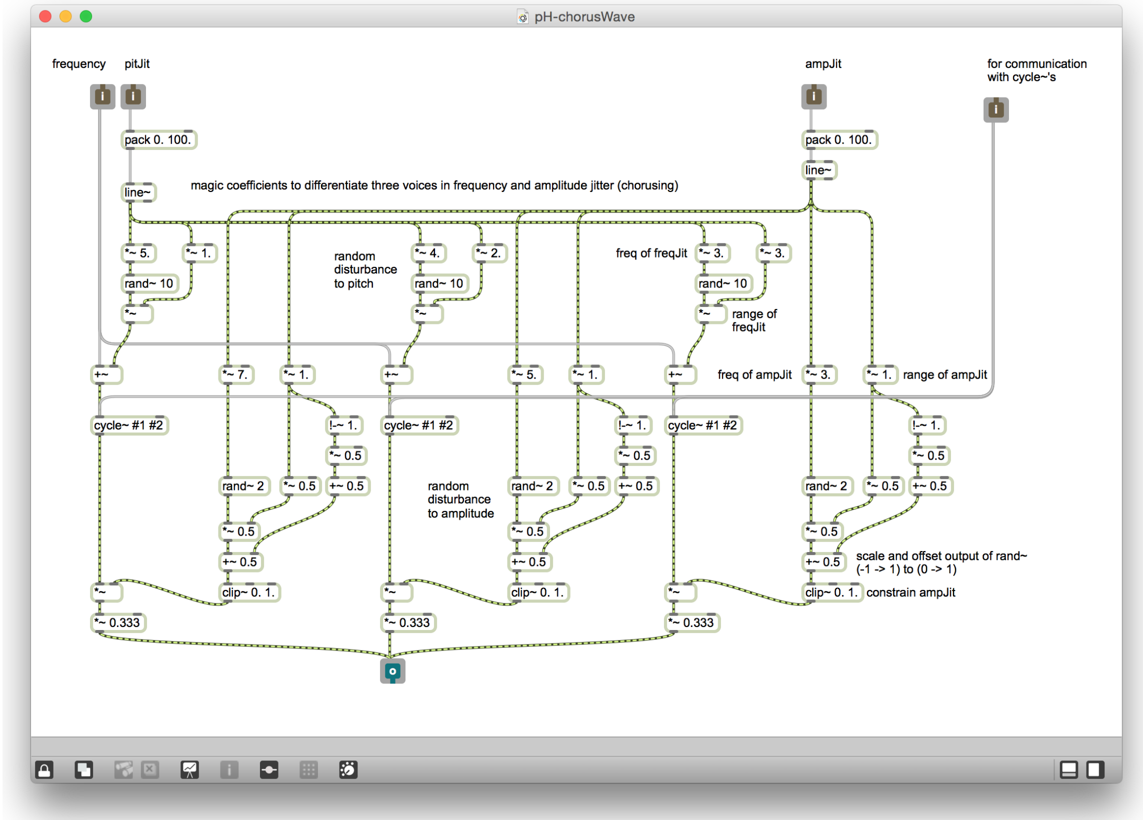


Figure 64. pH-chorusWave (abstraction within multiWave4): Three-voice, chorusing wavetable synthesizer.

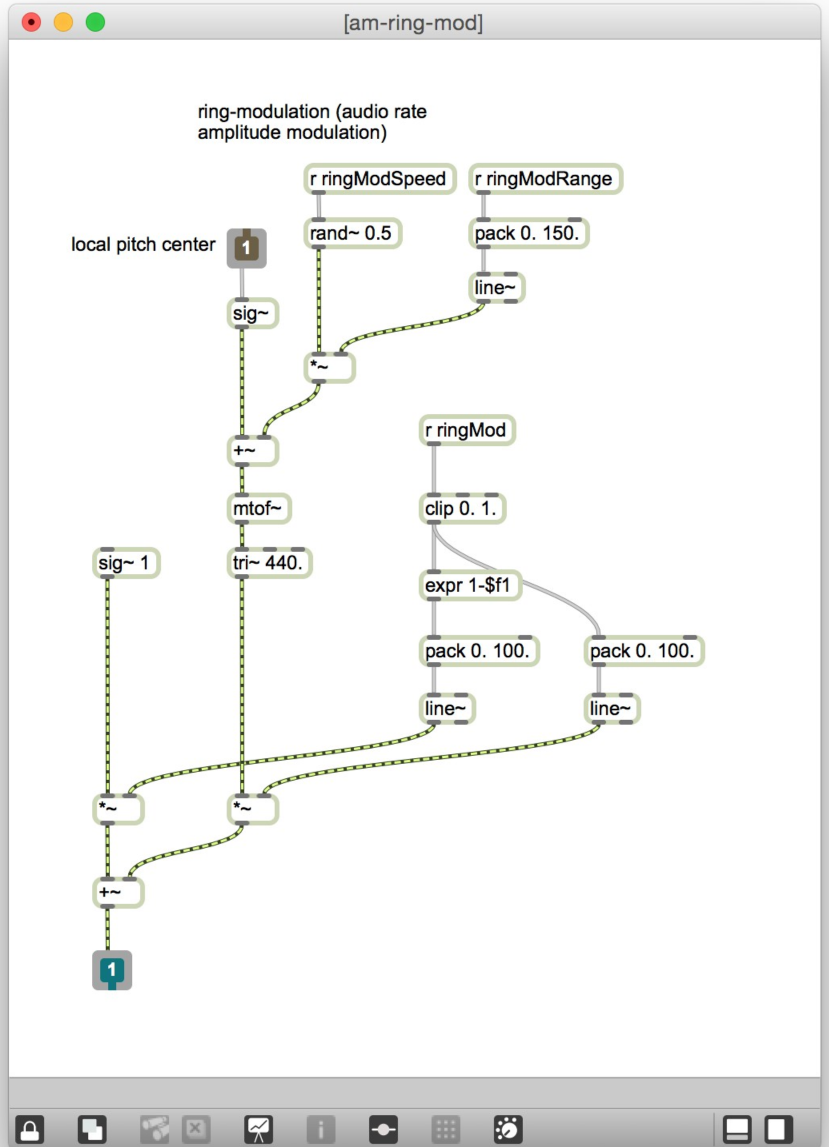


Figure 65. am-ring-mod (sub-patch of sound-maker): Produces an audio signal with audio-rate variations to multiply by the wavetable synthesis-generated audio signal.

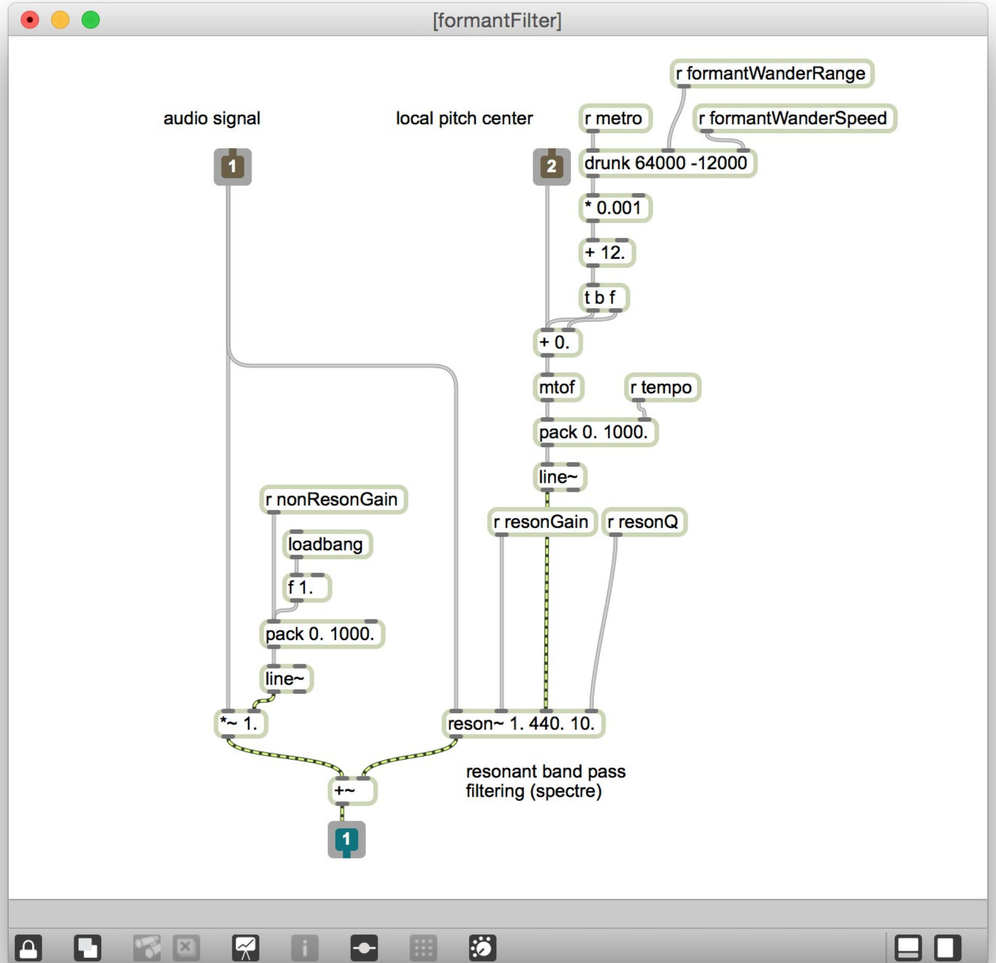


Figure 66. formantFilter (sub-patch of sound-maker): Applies a resonant band-pass filter to the audio signal chain, with varying degrees of strength according to the *spectre* variable.

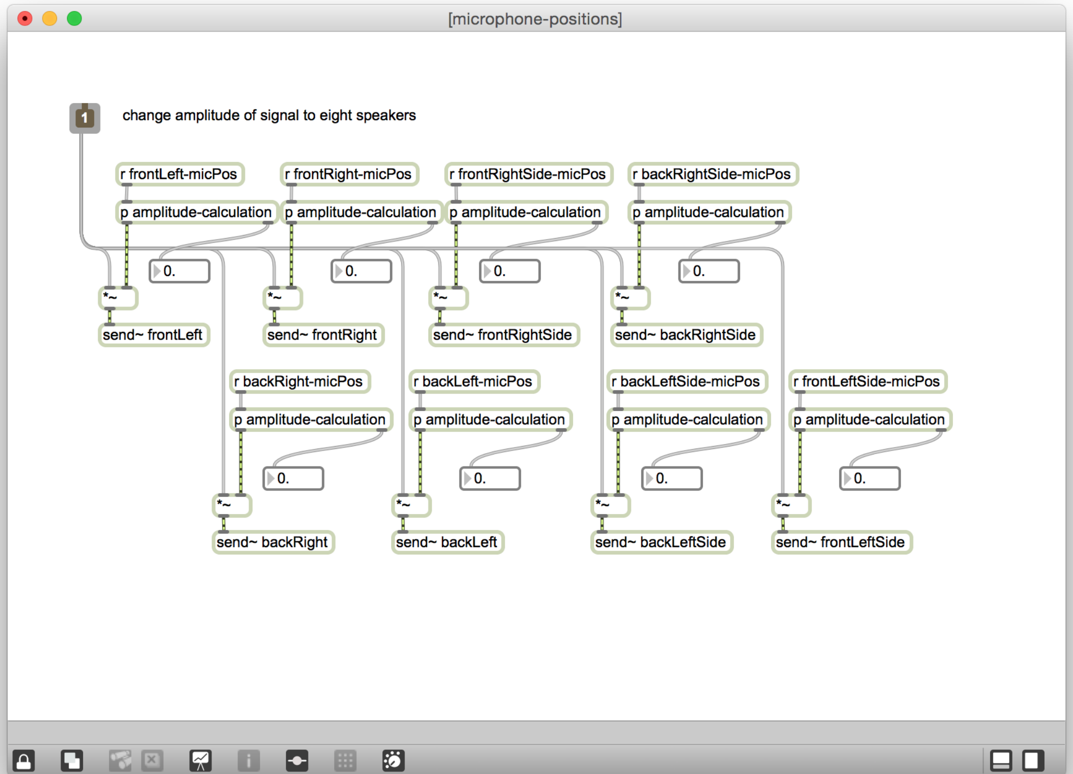


Figure 67. microphone-positions (sub-patch of sound-maker): Calculates signal strength to send to each of the virtual microphones based off of their distance to this module.

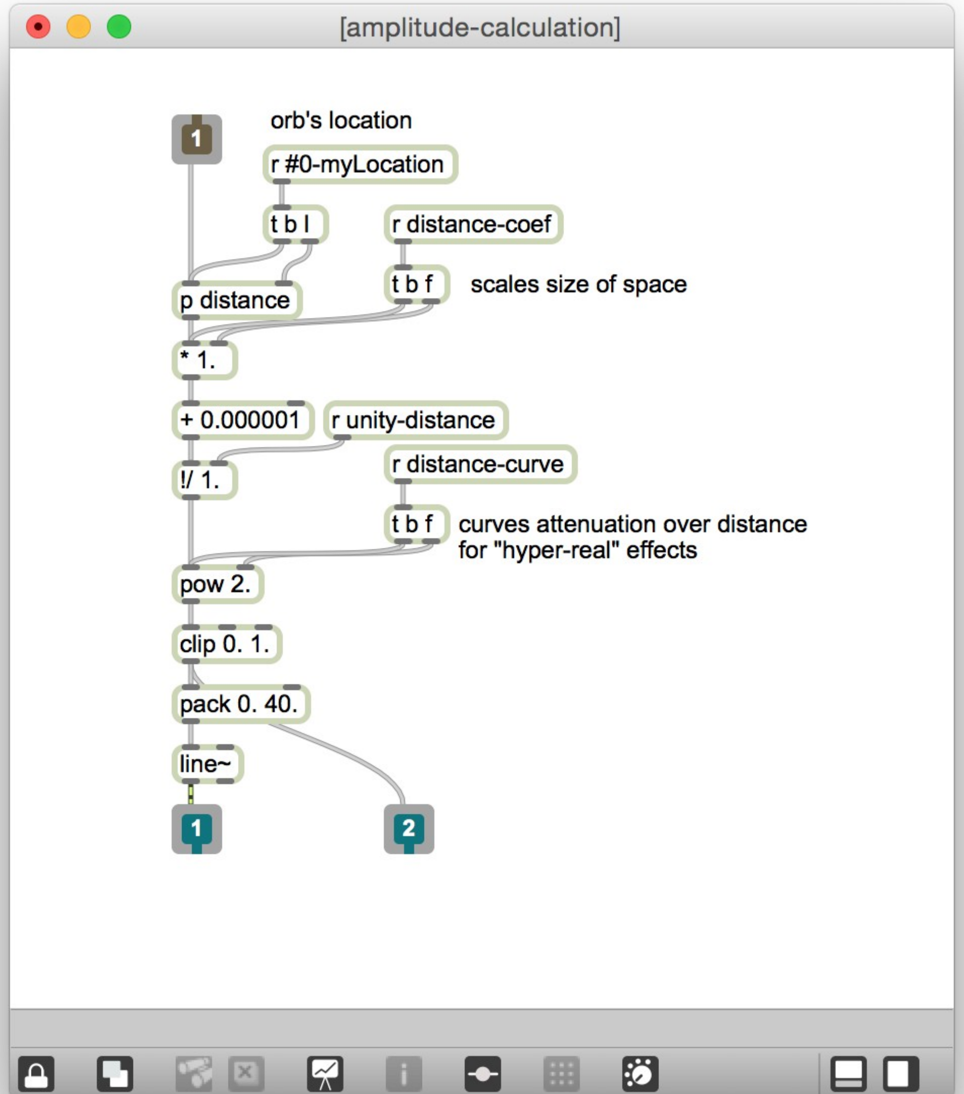


Figure 68. amplitude-calculation (sub-patch of microphone-positions): Example of individual amplitude calculation for each virtual microphone.

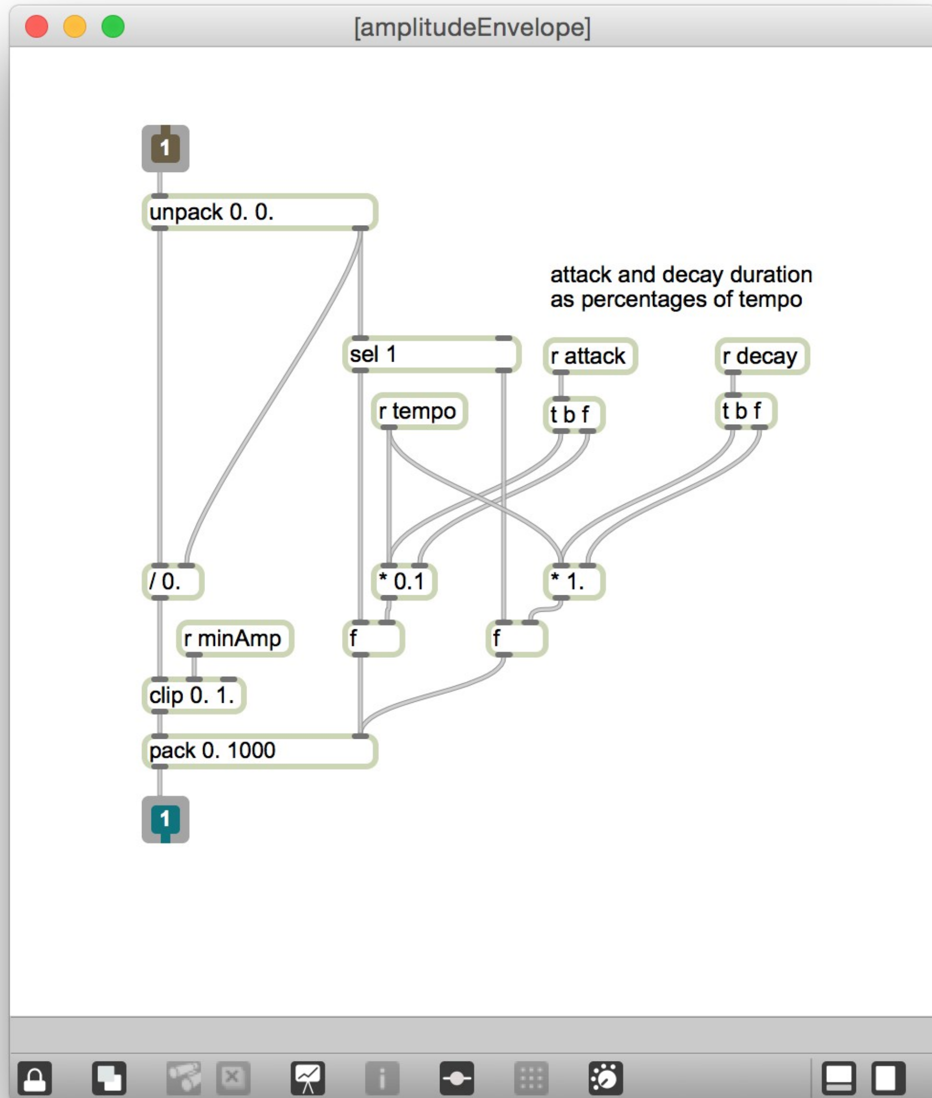


Figure 69. amplitudeEnvelope (sub-patch of sound-maker): Applies an amplitude envelope to the wavetable synthesis based on cellular activity.

Figure 70. getNeighborhoodValues (sub-patch of hex-cell): Calculates the unique identification numbers of all adjacent cells to this cell, and queries their states in the hex-cell-data table.

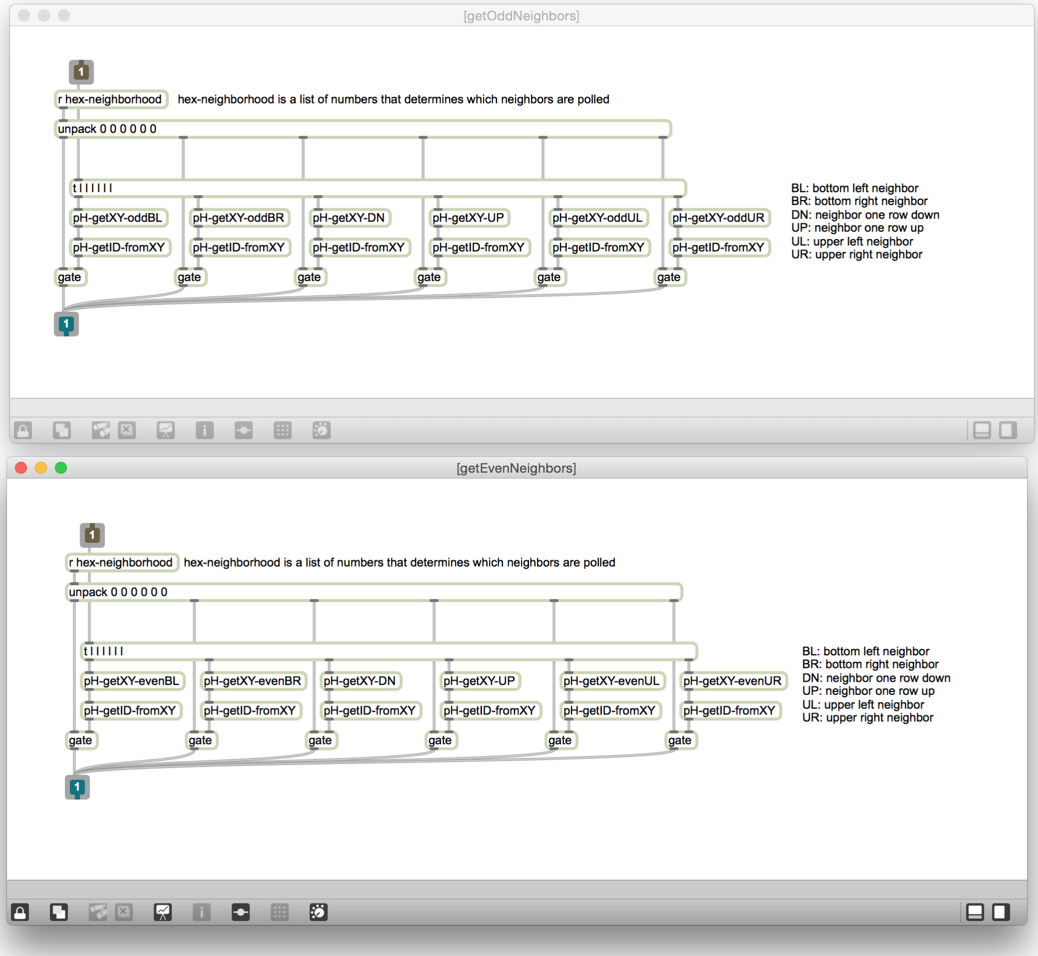
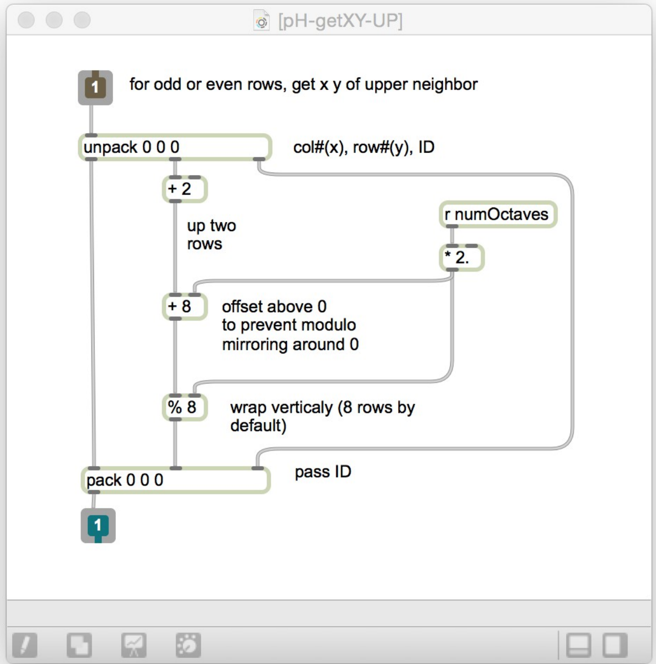


Figure 71. getOddNeighbors and getEvenNeighbors (sub-patches of getNeighborhoodValues): For cells in odd or even rows, calculates the unique identification numbers for all six neighbors. The gates are controlled by the hex-neighborhood list, which allows the user to ignore specific neighbors for later calculations.



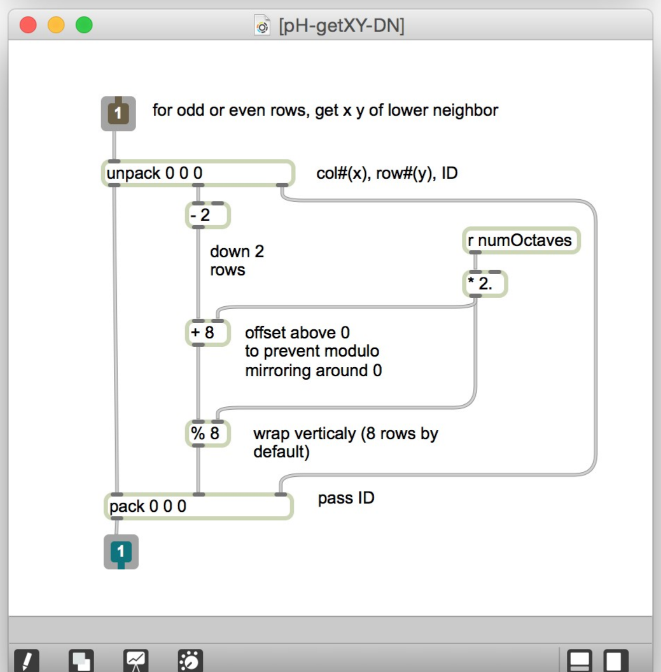


Figure 72. pH-getXY-UP and pH-getXY-DN (abstractions within both getOddNeighbors and getEvenNeighbors): Calculates the column and row numbers for the neighbors above and below the current cell. Used in both odd and even rows.

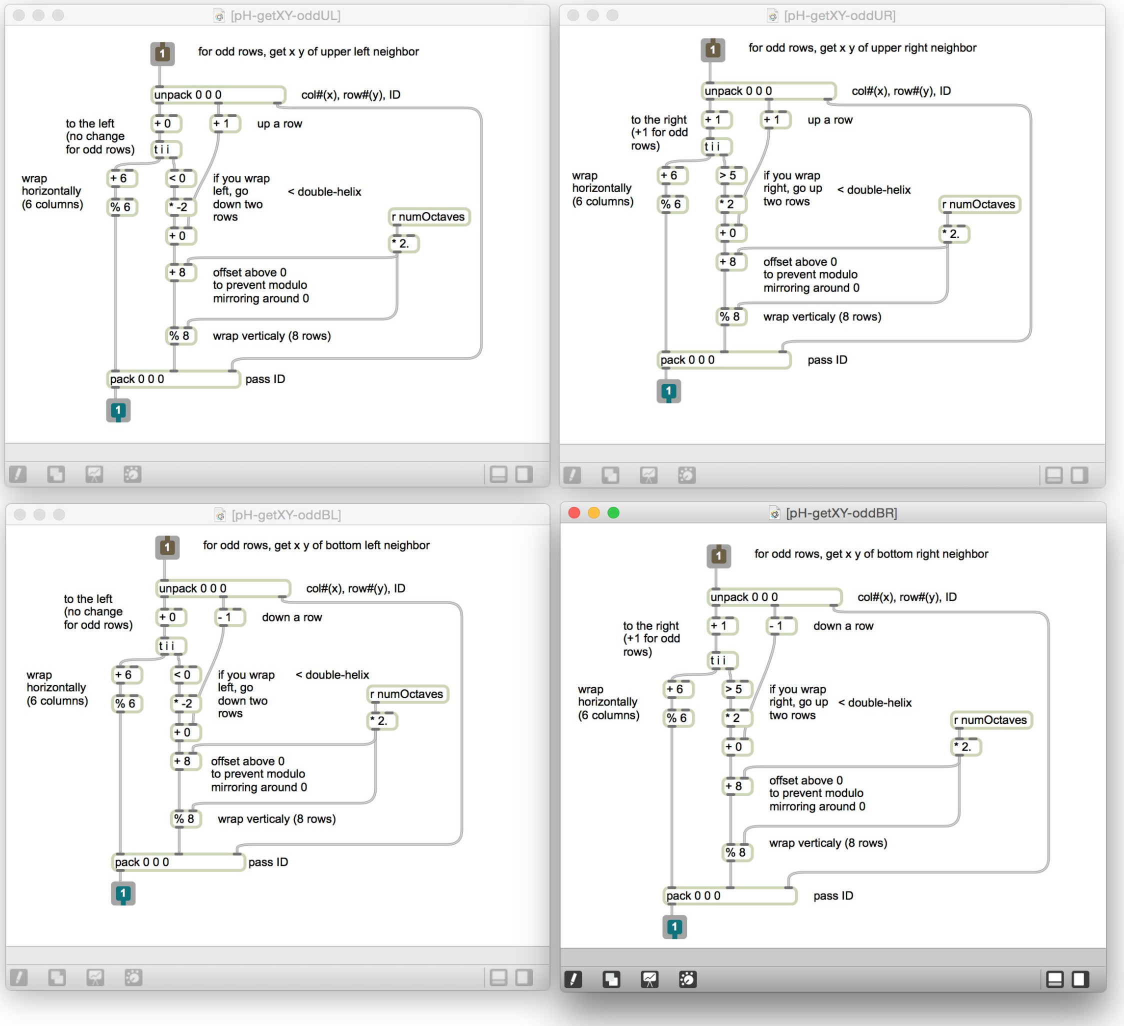


Figure 73. pH-getXY-oddUL, pH-getXY-oddUR, pH-getXY-oddBL, and pH-getXY-oddBR (abstractions within getOddNeighbors): Calculates the column and row numbers for neighbors of cells in odd rows. Note the use of relational operators to account for double-helical wrapping.

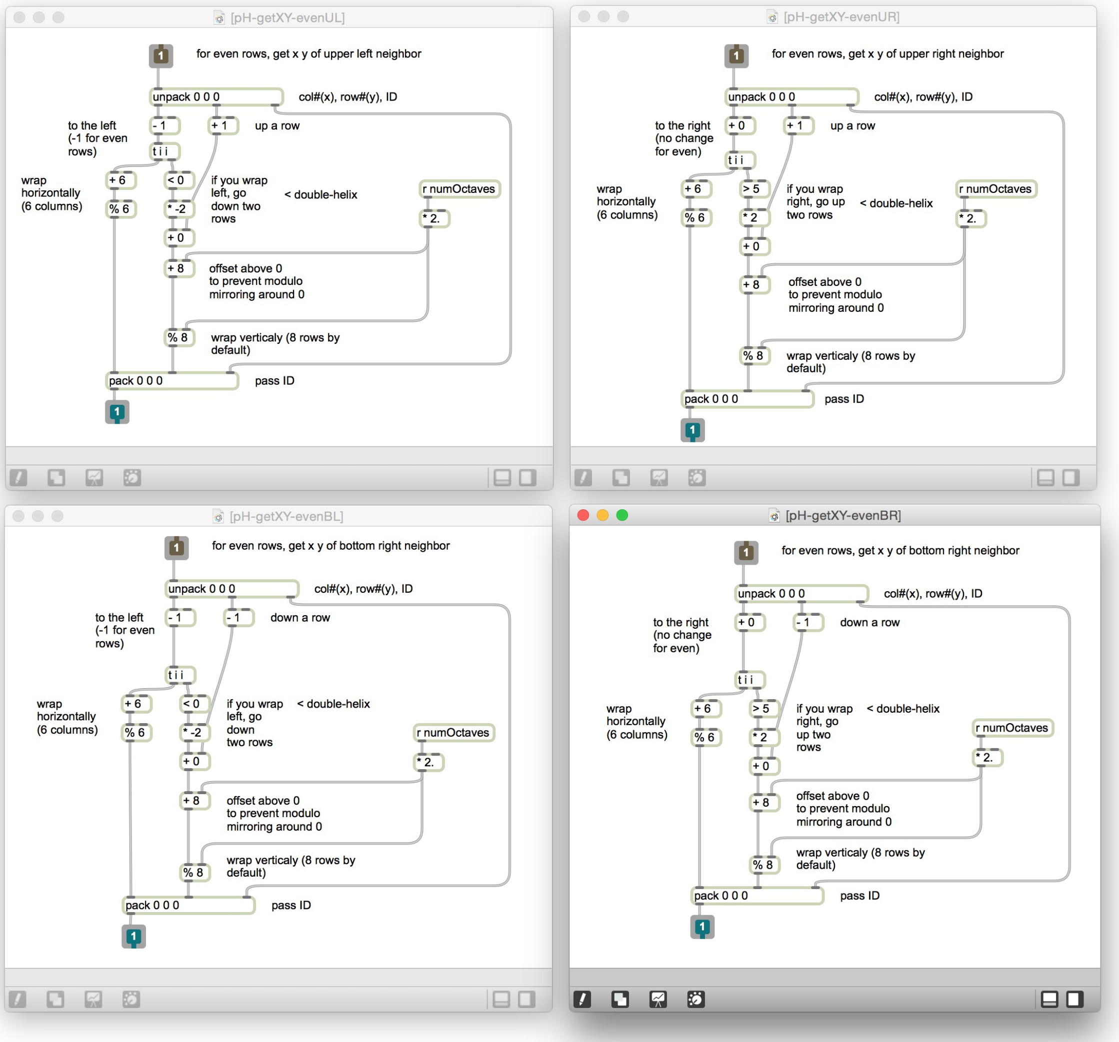


Figure 74. pH-getXY-evenUL, pH-getXY-evenUR, pH-getXY-evenBL, and pH-getXY-evenBR (abstractions within getEvenNeighbors): Calculates the column and row numbers for neighbors of cells in odd rows. Note the use of relational operators to account for double-helical wrapping.

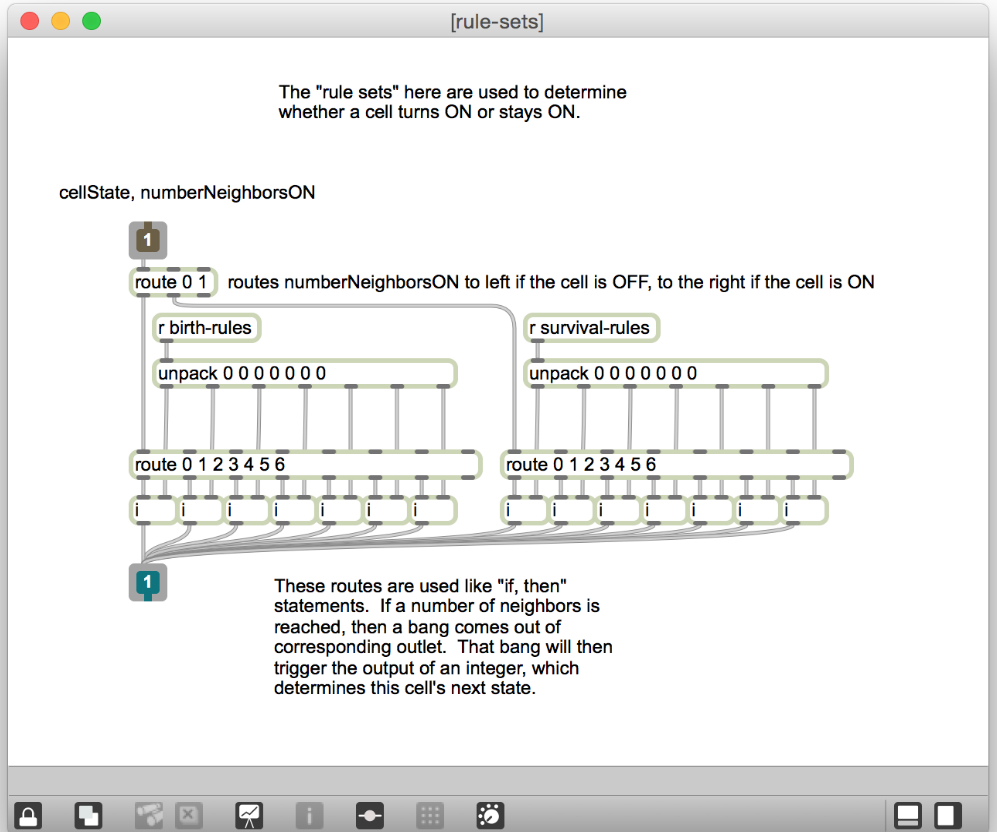


Figure 75. rule-sets (sub-patch of hex-cell): Calculates a cell's next state based on its current state and the number of neighbors currently active.

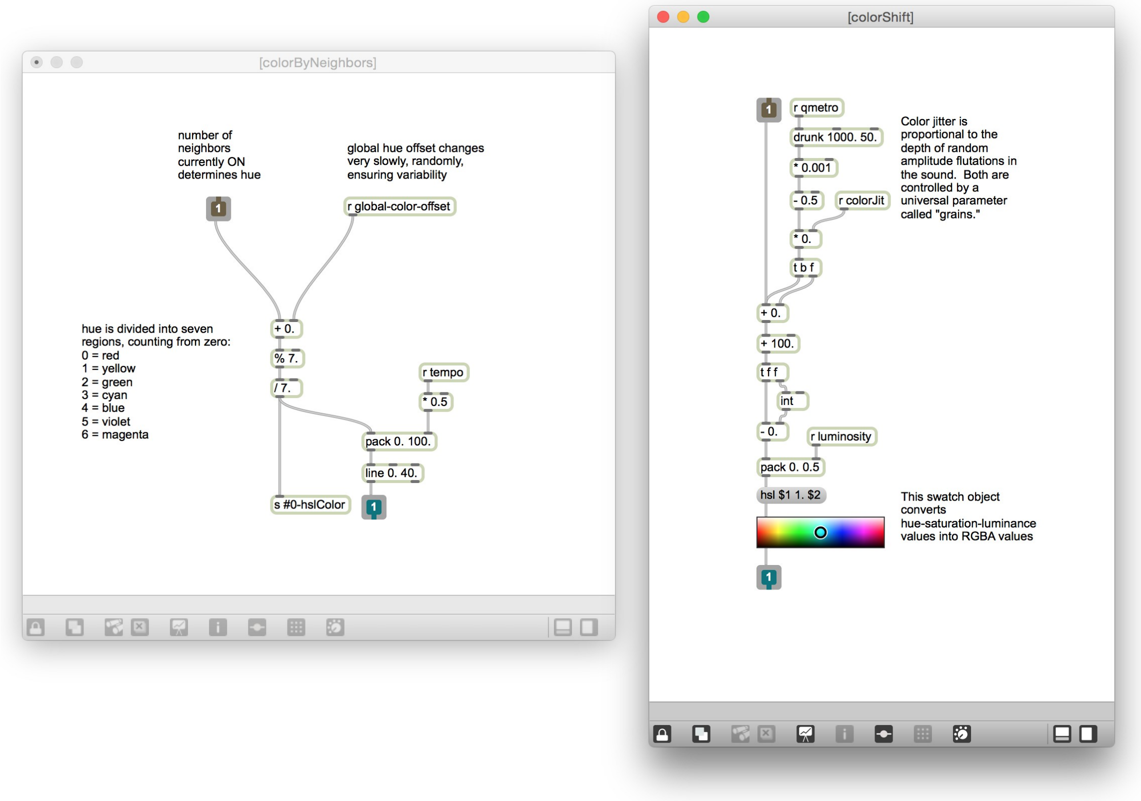


Figure 76. colorByNeighbors and colorShift (sub-patches of grid-shaper): colorByNeighbors calculates a hue for each cell based on the number of its neighbors currently active. colorShift introduces rapid shifting in color to accompany rapid changes in amplitude of the sound.