

© Copyright 2024

Daniel Peterson

# **Vanishing Portals**

Daniel Peterson

A dissertation

submitted in partial fulfillment of the  
requirements for the degree of

Doctor of Philosophy

University of Washington

2024

Reading Committee:

Richard Karpen, Chair

Juan Pampin

Afroditi Psarra

Program Authorized to Offer Degree:

Digital Arts and Experimental Media

University of Washington

**Abstract**

Vanishing Portals

Daniel Peterson

Chair of the Supervisory Committee:

Richard Karpen

Digital Arts and Experimental Media

*Vanishing Portals* is a 3D music composition made in the acousmatic tradition of sounds which are heard but not seen. The following document is an attempt to capture the compositional processes, the artistic, historical, and technical, that are intertwined, and sometimes ephemeral. The writings weave self-reference in art, self-similar structures in macro- and micro-sound, the infinity of space and the techniques of spatial sound design using ambisonics.

## ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Richard Karpen, for sharing with me your deep understanding of art, music, and life and for your continual support of my work, both through praise and critique. I would also like to thank Dr. Juan Pampin for your guidance, wisdom, and support, and for the opportunities you continue to provide. I would like to thank Dr. Joseph Anderson for your patience with my work with ambisonics, sound synthesis and processing. Thank you for providing an endless “bucket of fish”.

I would like to thank a few of my DXARTS colleagues, Adam Hogan, Martin Jarmick and Marcin Pączkowski.

I would like to thank my family for their constant support and encouragement. As we say, family is everything.

Last and most import, my wife, Adrienne Peterson. You are my support. I could not have done this without you.

## Introduction

“...buried in the nameless black of a name.” Mark Z. Danielewski, *House of Leaves*

I have begun to realize (I couldn't possibly have known this before) that my work is centered around the idea of the imagined, uncanny, and impossible realities that are no less real than the unimagined. They mirror the books within books of Borges' *The Garden of Forking Paths* and the pseudo-academic manuscripts with fractured narratives spiraling down the impossibly horrific labyrinth of corridors (pages) of Danielewski's *House of Leaves*. They are inspired by the multilayered narratives of *One Thousand and One Nights* and the unfathomable two suns above the impossibly unattainable yet un-hyperbolically perfect love mystery in Casares' *The Invention of Morel*. These realities confound and confuse yet make perfect sense.

In *Vanishing Portals* these realities are turning inward, spiraling into the labyrinth of being, traversing the discontinuities of consciousness and identity, “buried in the nameless black of a name.” The piece travels through the corridors of the mind, becomes suspended in the ephemeral space of memories, forever seeking the portals in space and time that lead to the “misweaves”, the places where things break down, the outliers, the discarded data. It is a labyrinth of musical memory, simultaneously musical and idiosyncratic.

This dissertation documents my work on and compositional thought processes in making *Vanishing Portals*. To document the beginning is an impossible task. All of my work builds upon previous work; life itself builds on its ancestors and so on. I am

continually reminded of Carl Sagan and his idea that “if you wish to make apple pie from scratch, you must first invent the universe.”<sup>1</sup> If we wish to discover the origin of something, we forever have to keep going back in time. The first chapter spins around an artistic phenomenon that I find seemingly everywhere I looked. I look at it from three different perspectives and track its various forms in music and literature. The third chapter describes the piece in detail, including the structure and the works that directly influenced it, both of my own work and others.

---

<sup>1</sup> Sagan, Cosmos

# TABLE OF CONTENTS

<b>I. The Spiral</b>	
1.0 Scales and Infinity	1
1.1 Self-Reference and Strange Loops	2
1.2 Self-Reference in Literature	5
1.3 Art within Art	12
1.3.1 Literature within Literature	12
1.3.2 Music within Music	14
1.4 The Spiral	19
<b>II. Technical Research</b>	
2.0 Introduction	24
2.1 Sound Space Localization	24
2.2 Spatializer	30
2.2.1 Delay-based Panner	30
2.2.2 Distance Modeling	31
2.2.3 Doppler Shift with Delays	33
2.2.4 Reverb	35
2.2.5 Ambisonics	36
2.2.6 Spatializer with Reverb	40
2.3 Room Impulse Responses	43
2.4 Flock	48
<b>III. Vanishing Portals</b>	
3.0 Introduction	50
3.1 The Garden of Earthly Delights	50
3.2 Recording as Composition	51
3.3 Feedback	55
3.4 Recording as Composition, A Return	57
3.5 Spatialization as Down, Up, Down	58
3.6 The Portals Return	64
3.7 The Structure of Vanishing Portals	64
3.8 Future Work	68
3.9 Why Music?	69
Bibliography	71

## LIST OF FIGURES

Figure 1. M.C. Escher, Waterfall.....	3
Figure 2. Shepard Tone.....	20
Figure 3. Beethoven Symphony No. 7.....	21
Figure 4. Beethoven Symphony No. 5.....	22
Figure 5. Visualization of ITD and IID.....	25
Figure 6. Direct Sound vs Reflections Close Source .....	26
Figure 7. Direct Sound vs Reflections Distant Source.....	27
Figure 8. Blauert's High Frequency Absorption Curve.....	28
Equation 1. High Frequency Absorption.....	28
Figure 9. The Doppler Effect.....	29
Figure 10. Delay Panner.....	30
Figure 11. ITD Table.....	31
Equation 2. High Frequency Absorption.....	32
Figure 12. Distance.....	32
Figure 13. Doppler Shift Chart.....	33
Figure 14. Doppler Shifter.....	34
Figure 15. ATK Zoom.....	38
Figure 16. Zoom Distortion Angles.....	39
Equation 3. Cartesian to Polar.....	39
Figure 17. HoaSpatializer.....	41
Figure 18. HoaSpatializerReverb.....	42
Figure 19. RIR Diagram.....	43
Figure 20. HoaDistRIR3.....	45
Figure 21. HoaSpatializerRIR3.....	46
Figure 22. HoaRIR.....	48
Figure 23. Flock.....	49
Figure 22. The Garden of Earthly Delights.....	51
Figure 25. Eigenmike.....	52
Figure 26. Zolzer Feedback Network.....	55
Figure 27. FeedbackFreqShift.....	56
Figure 28. ValhallaFreqEcho.....	56
Figure 29. Chowning Lissajous.....	61
Equation 4. Lissajous.....	61
Figures 30-2. Chowning Lissajous.....	62
Figure 33. <i>Vanishing Portals</i> Structure.....	65

# I. The Spiral

---

## 1.0 Scales and Infinity

In the 5th century BC, the Greek philosopher, Zeno of Elea, formulated his “immortal” paradox, Achilles and the Tortoise, which “denied that anything could happen in the universe,” or more specifically, that motion through space is an illusion and does not exist (Borges and Weinberger, 43).

In his essay, *The Perpetual Race of Achilles and the Tortoise*, Jorge Luis Borges describes the paradox, “Achilles, symbol of speed, has to catch up with the tortoise, symbol of slowness. Achilles runs ten times faster than the tortoise and so gives him a ten-meter advantage. Achilles runs those ten meters, the tortoise runs one; Achilles runs that meter, the tortoise runs a decimeter... ad infinitum, so that Achilles can run forever without catching up.” Borges then explores Bertrand Russell’s refutation of the paradox, that within an infinite series of numbers, “there are as many odd numbers as there are even,” even though the actual quantity is indefinite, or “that there are as many multiples of 3018 as there are numbers.” Borges declares that “the precise quantity of points in the universe is the same as in a meter in the universe” (43-47). Thus, in the first subsection where Achilles travels ten meters, and the tortoise travels one, both indeed cross an infinite number of points. The difference between these infinite points lies in their scale. The universe itself can be viewed as different scales of the infinite.

---

## 1.1 Self-Reference and Strange Loops

Douglas R. Hofstadter defines self-reference in the article “On Self-Referential Statements” in his book *Metamagical Themas: Questing for the Essence of Mind and Pattern*:

“Self-reference is ubiquitous. It happens every time anyone says ‘I’ or ‘me’ or ‘word’ or ‘speak’ or ‘mouth.’ It happens every time a newspaper prints a story about reporters, every time someone writes a book about writing, designs a book about book design, makes a movie about movies or writes an article about self-reference. Many systems have the capability to represent or refer to themselves somehow, to designate themselves, or elements of themselves, within the system of their own symbolism. Whenever this happens, it is an instance of self-reference.” (Hofstadter, 1985, 7)

In the article, Hofstadter explores various self-referential statements, such as “This sentence no verb”, “The reader of this sentence exists only while reading me” and a favorite of mine “This inert sentence is my body, but my soul is alive, dancing in the sparks of your brain”. The real fun begins when these self-referential statements turn paradoxical.

“That paradox is the so-called *Epimenides paradox*, or *liar paradox*.

Epimenides was a Cretan who made one immortal statement: ‘All Cretans are liars.’ A sharper version of the statement is simply ‘I am lying’ or, ‘This statement is false’” (Hofstadter, 1979, 17). These statements are paradoxical; if Epimenides is himself a

Cretan, is he lying when he says “All Cretans are liars”? If “This statement is false”, then would it be true? If a false statement is saying it is false, then it must be true, but if it is true, then it is in fact false, and so on. This is what Hofstadter calls a “Strange Loop”, and is defined as “[a] phenomenon [that] occurs whenever, by moving upwards (or downwards) through the levels of some hierarchical system, we unexpectedly find



Figure 1. M.C. Escher, Waterfall

ourselves right back where we started” (Hofstadter, 1979, 10). Hofstadter gives many examples of these strange loops in the music of Bach, the drawings of Escher, and the mathematics of Gödel in his book *Gödel, Escher, Bach : an eternal golden braid* (GEB). M.C. Escher’s, *Waterfall* illustrates the strange loop; a waterfall that feeds

itself, that seemingly moves horizontally only, until the water falls vertically back into the horizontal.

Self-reference is historically important in music. A surface example is the repeating of a melodic phrase, but there are many others, some that can be quite complicated. These repetition self-references become markers of time, landmarks within the music to orient us that time has passed, something has happened, and now we are back in a place that we know and that we remember. More generally, we are rewarded for noticing self-references, for example, by being able to “sing-along” with the music, possibly on a first listen; the “singing” isn’t necessarily audible (following along mentally) or even conscious. The more complex or opaque the self-reference, though, the higher the reward, which often only comes after much time with the particular piece of music, whether with a recording, live performance or the score.

There is a quote “Lesser Artists borrow, great Artists steal” that is attributed to Russian composer Igor Stravinsky, but the origin of the exact quote is unknown<sup>2</sup>, and may have been stolen itself. Interestingly, there is no third option; artists will either borrow or steal. If we think of all of music history as a singular thing, self-reference can then be extended across pieces, genres, cultures, etc. and so “stealing” and “borrowing” are instances of self-reference. To follow with Stravinsky, “stealing” makes a great artist, but why? “Stealing” implies transfer of ownership, whereas “borrowing” does not. In an artistic sense, “stealing” means that the artist has taken

---

<sup>2</sup> Sagan’s apple pie?

something and made it their own, obscuring the self-reference and rewarding the astute listener for finding it.

Why are these loops important, and what is the point? While Hofstadter explores, in *GEB*, the idea that out of these strange loops human consciousness forms, I explore them in the structure and meaning of literature and music. Similar to the rise of consciousness, these self-references and strange loops are where artistic knowledge and meaning can hide. A paradox of this type of artistic and musical knowledge is that often they need to be experienced and resist being able to be adequately talked (or written) about.

---

## 1.2 Self-Reference in Literature

The story, *The Library of Babel*, by Jorge Luis Borges, begins with a revealing quote from the *Anatomy of Melancholy*, ““By this art you may contemplate the variation of the 23 letters...”” (Borges and Hurley, 112). Language consists of permutations or “variations” of letters that create meaning and, in the most basic sense, language is perceived through sight and also through sounds in your head created by the letters. Literature also has characters other than letters, punctuation and also spaces. In certain works there are also fonts and emphasis, such as *italics* or **bold**. Writers use these as their artistic scale. The permutations of these symbols carry meaning both through their linguistic definitions and by the structure of their layout and sequencing on the page.

*House of Leaves*, by Mark Danielewski weaves through multiple levels of narration. The core story centers around a fictitious documentary film, The Navidson Record, about a family moving into a new house and finds a door that opens into a pitch black corridor that seemingly is not really part of the house. The film documents the exploration of this hallway, that leads to more rooms and more hallways that can't possibly fit inside of the physical house. We are given an account of this film third handed. The "main" character, if there is one, of the novel, Johnny Truant, and a few friends break into the apartment of a recently deceased old man, Zampanó, where he finds and keeps an old manuscript, which is Zampanó's description and analysis of the film. Johnny presents to us readers this manuscript, filled with fictitious references in the footnotes, all while Johnny fills in the footnotes with his own story, which as time passes seems to mimic the events of the film. Johnny's and Zampanó's respective narrations are denoted by a change in font.

As the film progresses, the exploration of the hallway gets weirder and weirder, time stretches, compacts and stands still, all of which is mirrored in the literal placement of words on the page; some pages are blank, some pages have only a few words scattered across them and some are completely consumed by the footnotes and Johnny's story. The house in the film is the physical book, *House of Leaves*, and the reader is taken on the same journey as the family exploring the black corridor, weaving through footnotes, odd pages with words scratched out, words turned sideways, a single letter on a single page. The book is writing about itself.

Italo Calvino's collection of short stories, *Cosmicomics*, is threaded by "the nostalgic narrative of Qwfwq, a cosmic being who has existed since the dawn of time and finds himself manifesting at various epochs throughout universal history." The name Qwfwq is ambiguous; the name isn't pronounceable and so may be the placeholder for a cosmic, undefined being; it is also a palindrome so "no matter which direction one travels along it morphemes, the same pattern is deduced, a common property of strange loops." (Altomare, 2013, 218)

While Qwfwq takes on many different forms, most of which are never clearly defined, they all display human qualities and emotions. Calvino uses archetypal stories about love and friendship to explore the vastness of outer (and inner) space and its forms. In one story, *The Form of Space*, Calvino weaves a love story of desire and jealousy around three characters, Qwfwq, Ursula H'x, and Lieutenant Fenimore, who are free falling in parallel lines in space. As they fall, Qwfwq and Fenimore seem to compete for Ursula's attention, and Qwfwq exhibits the desire to be with her: "I, too, dreamed only of meeting Ursula H'x, but since, in my fall, I was following a straight line absolutely parallel to the one she followed, it seemed inappropriate to reveal such an unattainable desire" (Calvino, 1968, 116). As they continue to fall past universes and galaxies, Qwfwq becomes jealous realizing that if they fell infinitely that eventually their parallel paths would converge "at the very moment when Ursula H'x would cease to be alien to me, another alien with his thin black mustache would share our intimacies in an inextricable way" (117). Determined to reach Ursula, Qwfwq begins to realize that space is not empty because he is inhabiting it; he has an effect

on the shape of space and begins to find ways to navigate the space to fend off his adversary, Fenimore. The two soon find themselves in a battle traveling over canyons and river beds, and eventually the letters on the page itself:

“Lieutenant Fenimore and I, hiding behind the loops of the *l*'s, especially the *l*'s of the word ‘parallel,’ in order to shoot and take cover from the bullets and pretend to be dead and wait, say, till Fenimore went past in order to trip him up and drag him by his feet, slamming his chin against the bottoms of the *v*'s and the *u*'s and the *m*'s and the *n*'s which, written all evenly in an italic hand, became a bumpy succession of holes in the pavement” (123).

This strange loop via self-reference, literally referring to the letters on the page, further devolves into a commentary about written language and the shapes of letters themselves:

“...but I could seize her by the hair and bend her against a *d* or a *t* just as I write them now, in haste, bent so you can recline against them, then we might dig a niche for ourselves down in a *g*, in the *g* of ‘big,’ a subterranean den which can be adapted as we choose to our dimensions, being made more cozy and almost invisible or else arranged more horizontally so you can stretch out in it. Whereas naturally the same lines, rather than remain a series of letters and words can be drawn out in the black thread and unwound in continuous parallel, straight lines which mean nothing beyond themselves in their constant flow, never meeting, just as we never meet in our constant fall: I, Ursula H’x, Lieutenant Fenimore and all the others” (123)

The story has been turned inside out. The parallel lines of Qwfwq's fall turned into the letters on the page, as the reader participates in the fall by simply reading letters on a page. Qwfwq admits that he can control the "fall" with the mere shaping of lines on the page, providing a "g" in which the reader can "stretch out". The structure of the story has become literally embedded in the shapes on the page. And in true artistic sensibility the shapes become words again and describe that in fact they are parallel lines and, the reader's "fall" included, the characters will never meet "in their constant fall".

*The Library of Babel*, by Jorge Luis Borges, is a story in which "[t]he universe (which others call the Library) is composed of an indefinite, perhaps infinite number of hexagonal galleries" (Borges, 1999, 112) where "[e]ach wall of each hexagon is furnished with five bookshelves; each bookshelf holds thirty-two books identical in format; each book contains four hundred ten pages; each page, forty lines; each line, approximately eighty black letters" (113). With each book having a definite and finite structure the number of possible permutations is not infinite. Thus, at the end of the short story, the narrator postulates that the library's structure is infinite with ever repeating hexagonal rooms that lead to other hexagonal rooms and the books within it are not; "If an eternal traveler should journey in any direction, he would find after untold centuries that the same volumes are repeated in the same disorder—which, repeated, becomes order: The Order." (Borges, 1999, 118). In his dissertation *A Calculus of Fire*, Francis Altomare describes the strange loop in the structure of the Library, "[h]ere again there's a distinction between infinity as endless outwardness

and that special infinity encapsulated by strange loops. The infinity of the Library is a recursive infinity such that, if one proceeds in any given direction for some indeterminate amount of time, one will encounter the same pattern interminably. The Library quite literally folds back upon itself” (Altomare, 2013, 179).

*The Library of Babel* is also a labyrinth of meaning. Borges uses this fictional library to call into question the meaning of words. If “all books, however different from one another they might be, consist of identical elements: the space, the period, the comma, and the twenty-two letters of the alphabet” and “the Library is ‘total’—perfect, complete, and whole—and that its bookshelves contain all possible combinations of the twenty-two orthographic symbols” then the Library could contain indisputably meaningful books such as “the detailed history of the future, the autobiographies of the archangels”, “The Vindications—books *apologiæ* and prophecies that would vindicate for all time the actions of every person in the universe” (Borges, 1999, 115), but also an incoherent book such as one that “consisted of the letters M C V perversely repeated from the first line to the last. Another (much consulted in this zone) is a mere labyrinth of letters” (113). Such a nonsensical book lead some librarians to believe “ that books in themselves have no meaning” and as the narrator states that this argument “as we shall see, is not entirely fallacious” (114). Because of the existence of books such as the “M C V” and the “labyrinth of letters”, and that “[f]or every rational line or forthright statement there are leagues of senseless cacophony, verbal nonsense, and incoherency” (114), there are “infidels” that “claim that the rule in the Library is not ‘sense,’ but ‘non-sense,’ and that ‘rationality’ (even

humble, pure coherence) is an almost miraculous exception” (117). Yet the narrator refutes this:

“there is no combination of characters one can make—*dhcmrlchtdji*, for example—that the divine Library has not foreseen and that in one or more of its secret tongues does not hide a terrible significance. There is no syllable one can speak that is not filled with tenderness and terror, that is not, in one of those languages the mighty name of a god.” (117)

Above, Borges claims all words have meaning, however that meaning could very well misinterpreted:

“A number  $n$  of the possible languages employ the same vocabulary; in some of them, the symbol ‘library’ possesses the correct definition ‘everlasting, ubiquitous system of hexagonal galleries,’ while a library—the thing—is a loaf of bread or a pyramid or something else, and the six words that define it themselves have other definitions. You who read me—are you certain you understand my language?” (118)

We have made another strange loop. The existence of nonsensical books at first calls the meaning of all words into question. If there exists combinations of letters that mean nothing, and statistically those are most likely, then the system as a whole may be meaningless. But in the vast Library containing all possible books, surely those meaningless words have been defined somewhere and yet the meaning ascribed may not be what a reader thinks it is, as in Borges’ example of the definition of “library”,

we have gone from no meaning, to all words have meaning, to we may not know what the meaning is. And to finish it off, Borges asks the question of us, the reader, whether we are sure we actually know the meaning of the very words in *The Library of Babel*.

The last strange loop in *The Library of Babel* is one that might be easily missed. The narrator states “this pointless, verbose epistle already exists in one of the thirty volumes of the five bookshelves in one of the countless hexagons” (118). The short story that is about the Library is also in that very Library. The short story folds back upon itself.

---

## 1.3 Art within Art

---

### 1.3.1 Literature within Literature

Art within art, or meta art, is also a form of self-reference. Shakespeare often would have plays within his plays, such as in *Hamlet*, referencing not only a play within a play but often mirroring the exact plot of the “outer” play. One of the most dizzying instances of this meta art, in this case, metafiction, is the ancient compilation of stories, *One Thousand and One Nights*. The collection begins with the story of two brothers, one who is a king, who suffer a series of terrible events that leads the king to lay with a new virgin each night and then kill her. The vizier, in charge of finding the king a virgin, is left with no choice but to present his own daughter, Shahrazad, when she is the only virgin left in the city. Shahrazad plans to distract the king at night by

telling him story. Here we have our first story within a story. The labyrinth of meta stories continues as characters in Shahrazad's story begin to tell stories themselves. This structural meta story labyrinth is grounded in the self-referential, repetition and variation of the phrase "tell a story".

Borges's *The Garden of Forking Paths* also relies on a meta narrator. The story begins with a description of a fictitious excerpt from a real book, *The History of the World War*, by Liddel Hart, about an Allied offensive that had been delayed due to weather. What follows is a statement by a German spy, Dr. Yu Tsun, that sheds "light on the case", and also interestingly, "the two first pages of the statement are missing" (Borges, 1999, 119); the reader is plunged into the middle of an embedded second narration. This statement by Yu Tsun describes his mission as a spy to deliver a message back "to Berlin the secret name of the city to be attacked" (127). He flees from the Allied Capt. Richard Madden and ends up at the house of Stephen Albert, who so happens to be the keeper of the garden on forking paths, a labyrinth constructed by Ts'ui Pen, Yu Tsun's ancestor. The garden of forking paths turns out to be a novel, art within art, story within story. The novel, called a "contradictory jumble of irresolute drafts" by Yu Tsun, is a riddle about time, where each chapter is a forking in time:

"In all fictions, each time a man meets diverse alternatives, he chooses one and eliminates the others; in the work of the virtually impossible-to-disentangle Ts'ui Pen, the character chooses—simultaneously—all of them. *He creates*, thereby, 'several futures,' several *times*, which themselves proliferate and

fork... *all* the outcomes in fact occur; each is a starting point for further bifurcations” (125).

Similar to the Library, Ts’ui Pen attempted to write a novel that contains all possible times:

“*The Garden of Forking Paths* is an incomplete, but not false, image of the universe as conceived by Ts’ui Pen... he believed in an infinite series of times, a growing dizzying web of divergent, convergent, and parallel times. That fabric of times that approach one another, fork, are snipped off, or are simply unknown for centuries, contains *all* possibilities” (127).

The story within the story within the story ends with Yu Tsun killing Stephen Albert to reveal to Berlin, the name of the city of Albert.

---

### 1.3.2 Music within Music

In the 20th century, partly influenced by advances in technology and society, a new “Art of Noises” emerged in music. In 1913, Luigi Russolo, a member of the Italian Futurist movement that wished to reject history and tradition, published *The Art of Noises*, a manifesto on music that could be created with noises, inspired in part by the new noises of machines. Early music, he argues, is “a fantastic world superimposed on the real one, an inviolable and sacred world” (Russolo, 1986, 23). This early music was mostly interested in the “*unfolding in time*”, such as melody and polyphony, but that as music progressed:

“The desire, the search, and the taste for the simultaneous union of different sounds... was manifested gradually moving from the consonant triad to the consistent and complicated dissonances that characterize contemporary music. From the beginning musical art sought out and obtained purity and sweetness of sound... As it grows ever more complicated today, musical art seeks out combinations more dissonant, stranger and harsher for the ear. Thus, it comes ever closer to the *noise-sound*” (24).

Russolo describes a musical progression toward the spectral or timbral. Composers could use the spectrum, or the character of the sound, to convey meaning in music, and so could think vertically about sound, spectrally and texturally, and not be limited to just the horizontal “unfolding in time” music.

With the advancement of recording of sound into electric signals, in the middle of the 20th century, this spectral thinking about music would give rise to the “sound object” in *musique concrete* and to *elektronische Musik*. *Musique concrete* was pioneered by Pierre Schaeffer at Radiodiffusion Télévision Française in Paris, which grew into the Groupe de Recherches Musicales (GRM). Schaeffer conducted music and sound research with acousmatic sounds, recorded sounds of instruments and of other natural and manmade sounds. These recorded sounds were treated as a “instruments” that could be “played” and composed via various electronic, and later digital, manipulations, such as speeding up and slowing down the playback, removing the attack and only listening to the resonance of a percussion instrument, for example.

The result was a new musical language where the rhythm of the clicks and clack of a train, for example, could be a musical theme.

In contrast to the Schaeffer studio, in Cologne, a studio at Westdeutscher Rundfunk, most famously associated with Karlheinz Stockhausen, researched synthesizing sound using oscillators, noise generators, and filters. Instead of recording natural sounds, sine oscillators were combined at various carefully chosen frequencies and amplitudes to make new spectra, noise oscillators were shaped with amplitude envelopes to give new shapes and sweeps, and were also filtered at different frequencies and with different filter shapes to create even more new spectra. The schools of *musique concrete* and *elektronische Musik* were famously often at odds with one another, disagreeing about how electronic music should be composed, but their similarities lie in the fact that composers could manipulate sounds with new shapes in time and new spectra.

While the history of 20th century avant-garde music, and more specifically, electroacoustic music, is both well documented and outside the scope of this dissertation, the point is that music evolved quickly in this rich period, and often produced works that all but seemingly abandoned the deep musical history and knowledge of melody, harmony, traditional scales, and traditional instrument spectra; the question could be posited, *what is music?* Stockhausen and Schaeffer both helped develop this new electronic musical language that in a lot of ways follows the tradition of western art music composition, but at the same time can sound foreign and very much “amusical.” How can we return to this “music”?

Juan Pampin's *A Line* is a piece of music created from binaural recordings taken on the subway line "A" and various other places in Buenos Aires. The piece is "an imaginary journey through the city" (Pampin) and consists of several sound scenes that, through the use of custom algorithms, seamlessly transform in to each other. A main recurring scene is that of the subway itself, the "clickety-clack" of the train, the whirling of the train car speedy through various tunnels, and other subway related sounds such as doors opening and closing, and the hissing of the air powered brakes.

There are three scenes, however, which contain other music. The first happens toward the beginning of the piece where the rhythm of the train tracks becomes irregular and eventually transforms into the sounds of marching drummers. The second happens around 14:45 when walking on a normal street with cars, ambulances and people, and slowly the sounds of street musicians come into the scene. And the third happens immediately after the second with what sounds like a band with some clicking percussion (that again morphs into the clicking of the subway train). In these scenes, although Pampin has carefully selected, curated and in some cases manipulated them, he did not compose nor perform the recorded music. He has deliberately composed music within music.

Richard Karpen's *Life Study #5* is also composed of successive sound scenes that over time become manipulated and transform into one another. Self-described as "aural cinema", the piece has a clear sense of narration and of a forward trajectory. The first sound scene is that of a waving flag in the wind that has an irregular rhythm. For a moment, footsteps entered followed by the starting of a vehicle engine. This sets

up an expectation of a world of field recordings and the beginning of a journey. What happens next is that the noise of the engine morphs into a swirling texture that has a subtle hint of pitch, and as the large noisier texture fades, it gives way to what sounds like an orchestra warming up on stage. In the following scene we hear the distant, mangled sound of singing voices amongst swirling clicks and clacks, possibly of a train that builds into a climactic cacophony. A later scene is carefully composed of rhythmic drums and what could be the sound of an accordion playing rhythmic chords. The penultimate scene is a composed Bachesque organ fugue. In almost every scene, though much of it consists of “noises” or recordings, there are hints, whispers, of “music”, that of pitches, melodies and harmonies, culminating in the organ fugue, the music within music.

Bernard Parmegiani, a member of Schaeffer’s GRM, was an influential French acousmatic composer. In *Pop’eclectic* and *Du pop à l’âne*, the sound objects consist of samples of other music. *Pop’eclectic* is entirely composed of the soundtrack to *Je tu elles*, a film by Peter Foldés, which includes music by rock band Pink Floyd among others. In *Du pop à l’âne*, a title taken from the French phrase “Passer du coq à l’âne” which means “to change subjects”, Parmegiani creates a sonic collage with orchestral and pop music creating and “association of very different and unexpected styles of music” (Renouard-Larivière).

While these pieces contain literal examples of music within music, Parmegiani also creates moments of music within music by including parts of earlier pieces in a later piece, referencing himself. The beginning section of *L’Oeil Ecoute* reuses

material from *Pop'eclectic*. For his piece *Jazzex*, Parmegiani worked with a jazz quartet: saxophone, trumpet, bass, and drums. Parmegiani recorded the quartet improvising and then used that as the sound objects to compose the tape piece, that would then return and accompany the live quartet. The recordings of the saxophone play a major role in the 6th movement, *Conjugaison du timbre*, of his masterpiece *De Natura Sonorum*. The careful listener will notice these self-reference, self-samplings, and be rewarded with these hidden music within music moments.

---

## 1.4 The Spiral

The spiral is a common form in nature: snail shells, flowers and plants, pine cones, storms and hurricanes, and even galaxies. A spiral does not quite make a loop, but seen from a certain perspective, could be thought of as a circular structure that is ever expanding or traveling in a certain direction. From this same perspective, an infinite spiral has a self-similar structure in that as much as you zoom in and out, the spiral seems to look the same. And so the spiral is a circular loop that “seems” to be moving in a particular direction, but never really gets anywhere and just goes round and round.

In his monumental computer music piece *Mutations*, Jean-Claude Risset explores the spectrum of a bell using a computer for analysis and re-synthesis. The piece begins with discrete pitches taken from the spectral analysis of the bell. As the piece progresses Risset moves into continuous pitches and toward the end, creates the

famous endless glissando, or a Shepard tone, named after Roger Shepard, a cognitive scientist, who discovered the paradox in 1964, in which glissading pitches seem to

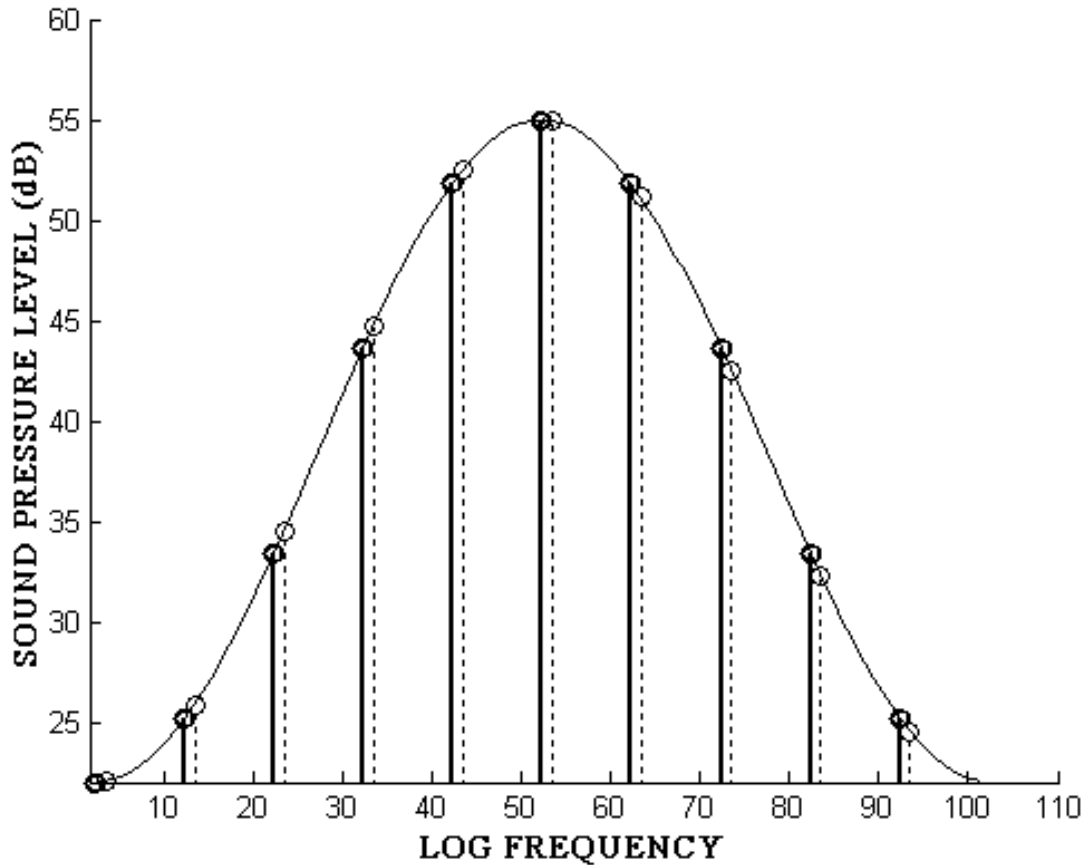


Figure 2. Shepard Tone Frequency Spectrum—<https://blog.soton.ac.uk/soundwaves/hearing-sounds/2-shepardrisset-tones/>

forever rise or fall. Analogous to the spiral moving around the barber's pole, the endless glissando is a paradox where individual pitches are rising or falling, yet seem to stay in place. Even more incredibly, Risset synthesizes tones that seem to rise but actually get lower in pitch, heard from 7:32-7:42.

A simple rising Shepard tone can be achieved by fading in/out rising sine tones spaced out harmonically, or in octaves. This can be seen in Figure 2. The point at which each sine tone reaches its loudest is the tonal center of the overall tone. What if



two octaves, instead of in Risset’s Shepard tone with the spacing at one octave, and with the different instruments playing after one another, there is a difference in spectrum. Still, while listening, the effect is quite apparent.

Another spiral-like moment happens toward the end of movement 4 of Beethoven’s 5th Symphony. This moving scale that starts with the violins and adds other instruments as it progresses, descends for four notes, then jumps up differing intervals, but lower than the starting note of the descending group of 4, descends 4 again, etc. until the final line descends eight notes (the score for the strings are seen in Figure 4). The aural result is a line that seems to descend for a while but doesn’t seem to get there, until it does. While not exactly the same technique as the Shepard tone, it still mimics an illusion of melodic motion in a particular direction that seems to spin and spin and delay getting to the final destination.

The image displays a musical score for five string instruments: Violins 1, Violins 2, Violas, Cellos, and Double Basses. The score covers measures 230 to 234 of the fourth movement of Beethoven's Fifth Symphony. The music is written in 3/4 time and features a descending scale with dynamic markings of *sf* (sforzando). The Violins 1 and 2 parts begin in measure 230, while the Violas, Cellos, and Double Basses enter in measure 231. The scale descends for four notes, then jumps up a different interval, and continues to descend in a series of steps, creating a spiral-like effect. The final note of the scale is in measure 234.

Figure 4. Beethoven Symphony No. 5 Movement 4 Measures 230-234—Brandon Amaro, 2022

In music, these spirals are forms of strange loops: musical phrases that seem to be moving in a particular direction but continually return to the starting point. Part of the reason for this is simply physiology; the human ear can only hear frequencies from approximately 20Hz to 20kHz, and so moving a phrase indefinitely, for example up in frequency, would end with inaudible sounds.<sup>3</sup> Although, even if it were possible to move forward in a particular direction indefinitely, what meaning would that provide? Repetition is where learning and knowing happen. In music, this happens within the same piece. In literature, I would hope, we return to read the same stories over and over, or quite possibly, the same stories get told and retold over and over. These repetitions are self-reference, and in Hofstadter's view of how consciousness is formed, these self-referential art works are conscious; they show that they are aware of themselves and become alive.

The spiral and strange loops are the periodicity of Borges' Library, the labyrinth of narration in *Thousand and One Nights*, the spinning of the galaxies and pulsars of Grisey's *Le Noire de l'Etoile*, the metamusic of Pampin and Karpen's aural cinema, the mirroring structures of narrative and meaning "buried in the nameless black of a name" (Danielewski, 2000, xxiii) of Danielewski's *House of Leaves*, and the orbit of the earth around the sun as the sun orbits around the center of the galaxy.

---

<sup>3</sup> In digital audio, we can synthesize frequencies up to half of the sampling rate due to the Nyquist theorem, so we couldn't ever rise in pitch anyway. And with acoustic settings, the pitches are limited by the construction of the instrument. Analog electronics can synthesize frequencies much higher, but that's beside the point.

## II. Technical Research

---

### 2.0 Introduction

As we will see in chapter 3, space, both virtual and physical, is integral to the realization of *Vanishing Portals*. The following chapter presents a few areas of technical research that rendered the piece possible. The first is a custom spatializer built in the SuperCollider audio programming language inspired by John Chowning's work with simulating moving sound sources. The second is an improvement on the spatializer using measured impulse responses of real spaces. Finally, the third is the use of the motion of flocking birds to control the virtual moving sound sources. But first, we will briefly look at how we hear in space in order to explain how the spatializer was designed.

---

### 2.1 Sound Space Localization

Hearing is a complex system of receiving sound stimuli via the body and outer ears, and decoding that stimuli in the inner ear and brain. We have two ears to help locate the incoming sound in space and while we can hear sounds coming from any direction, sounds outside of the horizontal plane can be difficult to locate. There are two main aural cues for sounds on the horizontal plane, the interaural time difference (ITD) and the interaural level difference (ILD).

The ITD happens when there is a difference in time of when the wavefront reaches each ear. This difference is then decoded to locate the sound in the horizontal plane; a sound to the left of the listener will reach the left ear first, and the difference in time will be dependent on the angle of arrival. The ILD is not as intuitive as the ITD. As sound moves through air it does lose intensity, but the distance between the ears does not cause a noticeable difference in intensity due to absorption; the intensity difference is due to the acoustic shadow of the head. The listener's head attenuates higher frequency sounds, usually above 500Hz and most noticeable above 1.5kHz, causing a level difference when the sound is not equidistant from each ear.

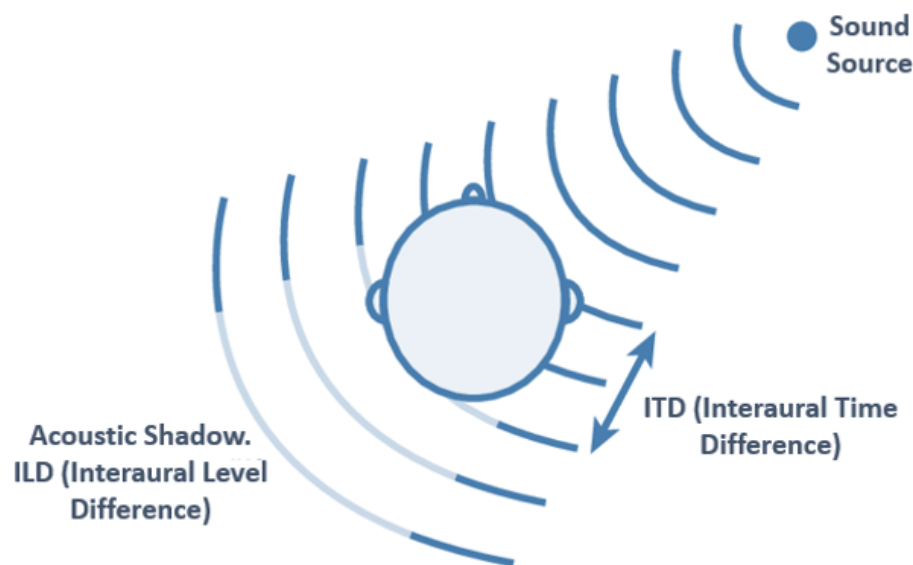


Figure 5. Visualization of ITD and ILD—<https://umicli.umi.us/discover/6231abedd4bad7d2be583aba/en>

In addition to the ITD and ILD, the body, neck, head, and outer ears also act as a filter for the incoming sound. When a sound source is equidistant from each ear, along the median plane, the ITD and ILD no longer provide any information. The

filter formed by the listeners body will give the most clues as to whether the sound is front, back, up or down. We can measure how this filtering changes with sounds at different locations by placing a microphone in each ear and recording sounds at various locations; the result is called the Head-Related Transfer Function (HRTF).

We can also discern far sounds from near sounds. There are a number of cues that help with this. Acoustic amplitude is inversely related to the distance. For example, a sound source that moves away to twice its original distance will be attenuated by approximately 6dB, or divided by 2. The ratio between the direct sound source and any reflections of sound objects in a particular space also gives us clues as to the distance. In unchanging acoustic spaces, the reflections, or reverb, will remain

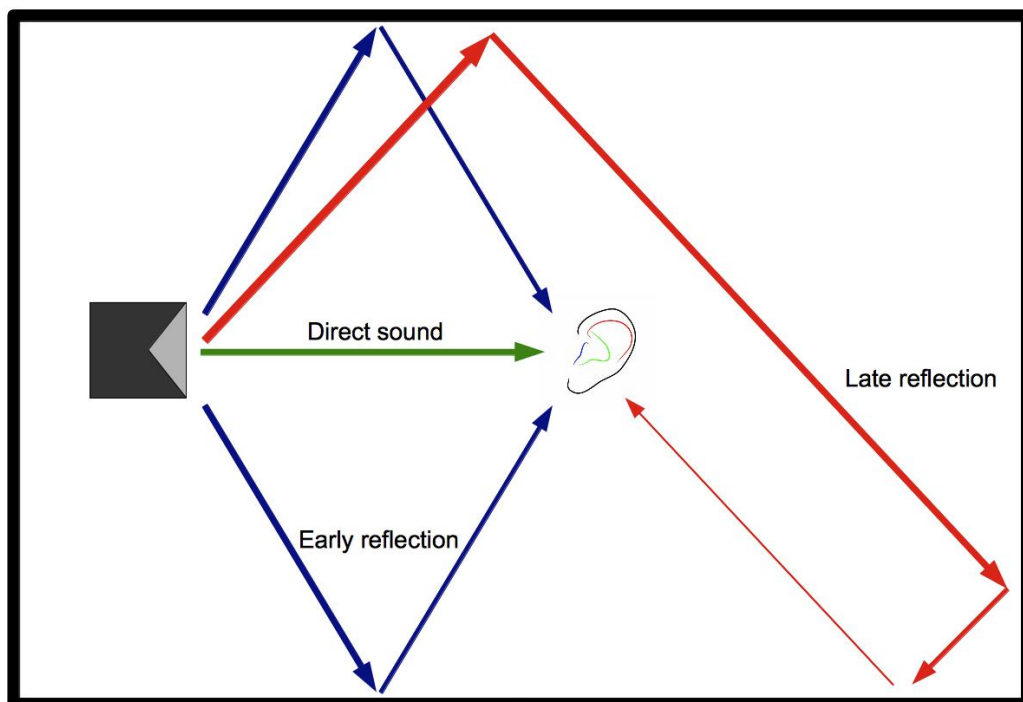


Figure 6. Direct sound vs. reflections of a close source—<https://beatsandbots.wordpress.com/2013/03/21/reverb-reverb-reverb-part-1/>

somewhat constant. Due to the attenuation of amplitude due to distance, closer sound objects will have a higher direct-to-reverb ratio and farther sound objects will have a lower direct-to-reverb ratio. In Figure 6, we can see that the difference of the length of the direct sound path and the early reflections is large, while in Figure 7, we see that the difference of the lengths is small; the listener is close to a reflective surface and so the difference between the direct sound and the early reflection is less significant. The attenuation of amplitude with distance is also frequency dependent at distances greater than 30 meters. The air absorbs higher frequencies more than lower

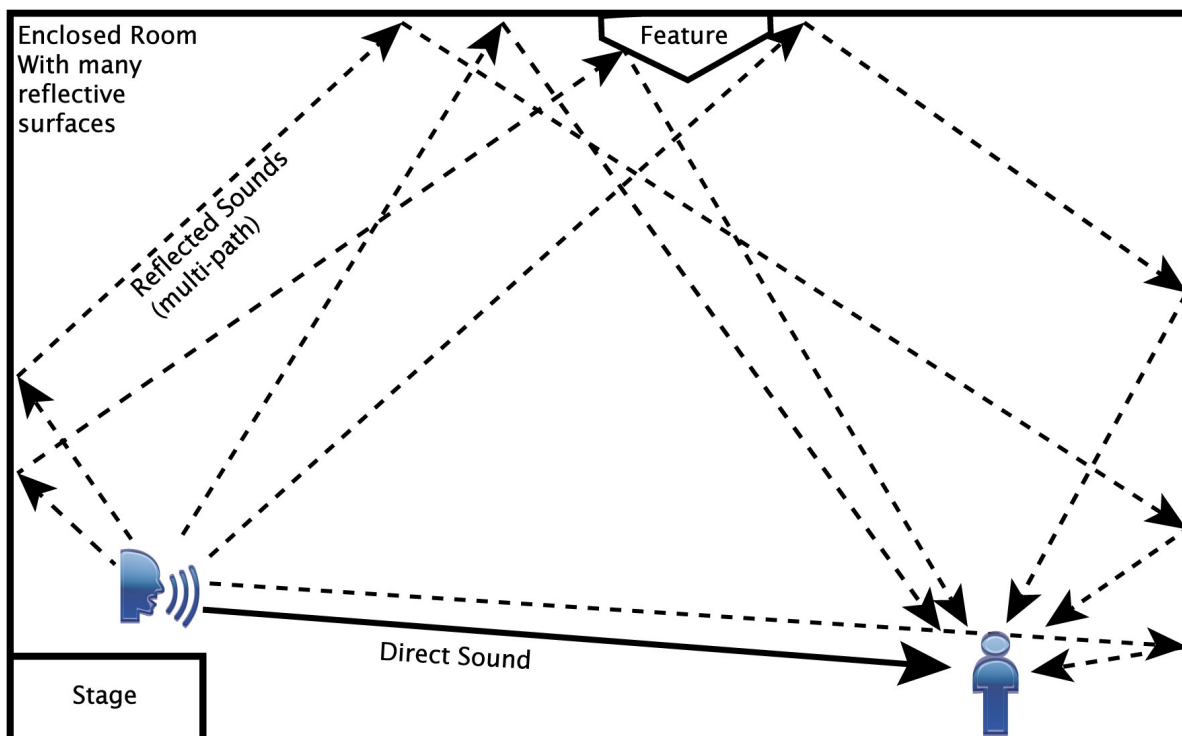
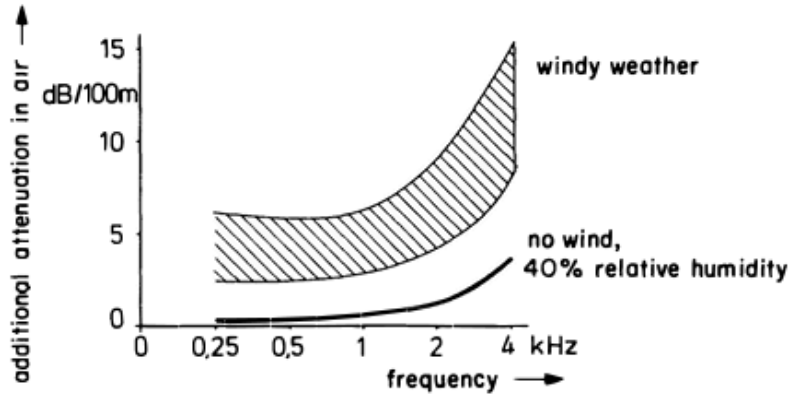


Figure 7. Direct sound vs. reflections of a distant source. <https://www.taesource.com/2020/08/all-about-reverb.html>

frequencies acting as a type of lowpass filter. In Jens Blauert's *Spatial Hearing: The Psychophysics of Human Sound Localization*, Figure 8 presents a high frequency absorption curve in db/100m with a relative humidity of 40 percent. This curve was

later approximated into an equation, Equation 1, by F. Richard Moore in *Elements of*



**Figure 2.58**

The attenuation of sound propagating freely in air (adapted from Ingård 1953). The attenuation caused by the divergence of spherical waves ( $1/r$  law) has already been subtracted. Relative humidity, 40 percent.

Figure 8. Blauert's High Frequency Absorption Curve, pg 126

*Computer Music*. While air conditions such as humidity change the rate of absorption, Equation 1 shows an approximation with static conditions, where  $f$  the frequency,  $m$  is the distance in meters, and  $dB$  is the attenuation in decibels. For example a sound signal with a frequency of 500Hz at 50 meters would have a 0.25dB attenuation.

$$dB/m = f/100,000$$

$$dB = f * m/100,000$$

Equation 1

Moving sources give clues due to the Doppler Effect. A sound source that is moving in a single direction is simultaneously moving toward and away from its own

wavefront due to sound emanating in all directions. The distance between wavefronts in the direction of the object are shorter and conversely the distance between wavefronts is longer in the opposite direction of the moving sound source. The shorter

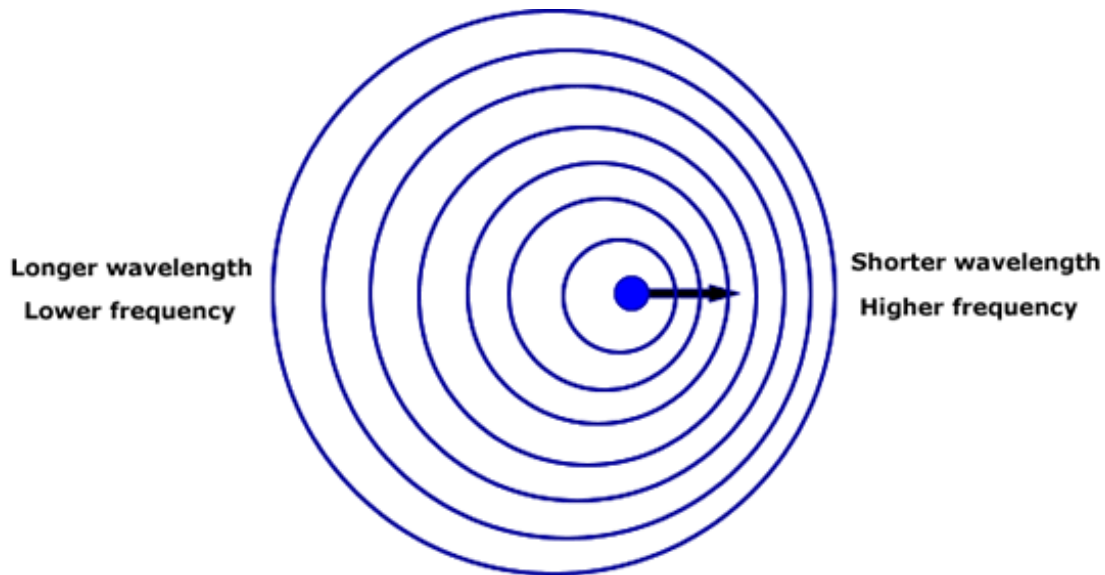


Figure 9. The Doppler Effect—[https://www.school-for-champions.com/science/waves\\_doppler\\_effect.htm#.WL9OChLyvdQ](https://www.school-for-champions.com/science/waves_doppler_effect.htm#.WL9OChLyvdQ)

wavelength results in a higher frequency and longer wavelengths give lower frequencies. As the sound moves toward the listener, the sound is higher in frequency, and as the sound moves past the listener, the frequency lowers.

While all of the above cues can help, spatial hearing, however, can take practice. Generally, hearing height and front-back sounds are less clear than those along the horizontal plane. The localization of sounds, therefore, is like a voting system. All of the cues are received and a decision is made about where the sound might be, where it might be moving. In the real world, we tend to move our bodies and heads to get a sense for the sound field that we are in and how to localize sounds within that field. Since our ears are pointed forward we often try to point our ears

toward the sound, and the changing cues that happen while we are moving help with this localization. Also, we are highly visually oriented and often sound sources that are ambiguous are located by sound and sight. Lastly, sound localization is heavily reliant on context and memory, e.g., the sounds of birds tend to be heard above our heads.

---

## 2.2 Spatializer

---

### 2.2.1 Delay-based Panner

Assuming an average distance of 0.20m between ears and a speed of sound at 343m/s, an ITD would be approximately 0.58ms assuming the sound is completely to the right or the left. For a sound located to the left of the listener, the right channel would be delayed at 0.58ms. A sound in the center would have no delays, equal time arrival for both ears, and a sound to the right would have a left channel delay of

```
PanDelay {  
    *ar { |in, pos = 0|  
        var left, right;  
        left = pos.linlin(-90, 0, 0.00058, 0);  
        right = pos.linlin(0, 90, 0, 0.00058);  
        ^DelayC.ar(in, 0.1, [left, right]);  
    }  
}
```

Figure 10. Delay-based panner implemented in SuperCollider

0.58ms, shown in figure 11. In the SuperCollider implementation, Figure 10, the user

inputs an angle from -90 to 90 degrees, where -90 indicates the sound will appear on the right and 90 on the left.

Source Location	Left Channel Delay	Right Channel Delay
Right	0.58ms	0.0s
Center	0.0s	0.0s
Left	0.0s	0.58ms

Figure 11. ITD for right, center, left sound locations for a 0.2m ear distance

---

### 2.2.2 Distance Modeling

Modeling distance uses two cues, amplitude attenuation and high frequency absorption. As we saw in the previous section, spherical waves diverge and attenuate inversely to the distance. High frequency absorption is dependent on air conditions such as wind and humidity. For the purposes of this spatializer, I assume static conditions seen in Equation 1. Figure 12 shows the result in SuperCollider code. Solving Equation 1 for frequency,  $f$ , results in Equation 2. Since I am using a lowpass filter (LPF), in SuperCollider to simulate the curve shown in Figure 8, and the cutoff frequency in a first-order lowpass filter is attenuated by 3dB, I solve the equation to find the frequency at which this 3dB attenuation would occur at a given sound distance,  $m$ , shown in Equation 2.

The distance simulator has a few controls,  $minDistance$ ,  $maxDistance$ ,  $minFreq$ , and  $maxFreq$ . Allowing distances less than 1 meter means that the sound signal would be amplified and possibly blow up at distances close to 0. It makes sense to limit this

to 1, but the user can decide how close the distance can be modeled. Maximum distance is also supplied so that sounds can always be heard where appropriate; large distances might make the sound inaudible. Similar to distance, maximum and minimum frequencies are required to allow the filter to work properly and not blow up the sound. The maximum chosen is the limit of human hearing as any filtering above

$$f = 3.0/m * 100000$$

Equation 2

20kHz would be inaudible. The minimum frequency is set to 600Hz as a personal preference and should be set by ear by the user. Future work on distance modeling would include further filtering for individual frequency components below certain thresholds.

```
Distance {  
    *ar { |in, distance, minDistance = 1, maxDistance = 100, minFreq  
= 600, maxFreq = 20000, absptCoeff = 100000|  
        var freq;  
        distance = distance.clip(minDistance, maxDistance);  
        freq = 3.0/distance * absptCoeff;  
        in = LPF.ar(in, freq.clip(minFreq, maxFreq));  
        in = in * distance.reciprocal;  
        ^in  
    }  
}
```

Figure 12. Distance modeling in SuperCollider

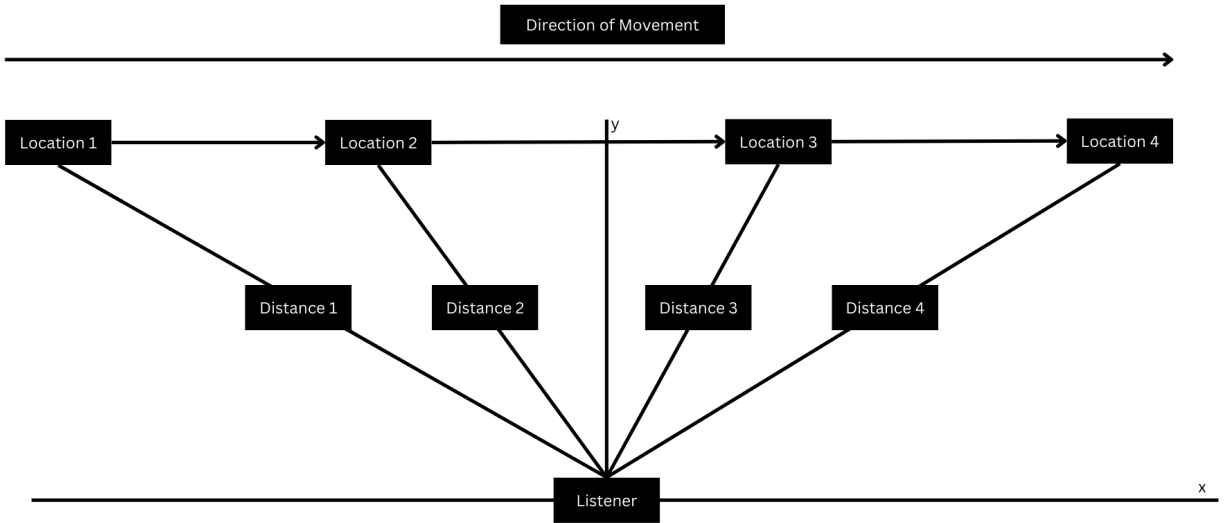


Figure 13. Doppler Shift using delays

### 2.2.3 Doppler Shift with Delays

Modeling the Doppler Shift is achieved by using a variable delay line. Imagine a sound is moving left to right at some distance in front of a listener as shown in Figure 13. When the sound is at “location 1”, it has “distance 1”. As sound propagates at approximately 343m/s, it takes some time to reach the listener, specifically, “distance 1” divided by the speed of sound. We can model this by introducing a delay with the correct time in seconds. The sound at “location 2” has a shorter “distance 2”. Calculating the delay in seconds again means our delay time is now shorter. As the sound moves from “location 1” to “location 2”, assuming we know the path, we can calculate all the delay times in between each location. When we use a variable delay line in a computer, we are storing sound samples into a buffer in order to play them at a delayed time. When we decrease the delay time, we are moving forward in time and

we need to read the samples in the buffer at a higher rate to “catch up” with the desired shorter delay time. This speeding up of the sound raises the pitch of the sound which is what we would expect the behavior of the sound in the real world to be, due to the Doppler Shift, illustrated in Figure 9.

The sound at “location 3” has the “distance 3”. Let’s assume that is the same as “distance 2” and our delay hasn’t changed. However, in between these locations the sound reached its closest point to the listener, directly in front, and then proceeds to move away from the listener. Our delay times would decrease until the this center point, and then start to increase back to “distance 3”. As the delay time increases, we now need to read samples in the buffer at a slower rate to wait for this increased delay time, which results in the pitch lowering, again as we would expect from the Doppler Shift. This Doppler Shift with a delay line is shown implemented in SuperCollider in Figure 14.

```
Doppler {  
    *ar { |in, distance, maxDistance = 500|  
        ^DelayC.ar(in, maxDistance/344,  
distance/344);  
    }  
}
```

Figure 14. Doppler shift implemented in SuperCollider

---

## 2.2.4 Reverb

When modeling sound in an enclosed space, the reverberation of the space gives cues to the listener about the distance of the sound as discussed in section 2.1. In *The Simulation of Moving Sound Sources*, John Chowning presents the idea of global and local reverb to simulate the distance of a sound object in such an enclosed space. Chowning suggests “some percent of the direct signal is scaled by  $1/\sqrt{\textit{distance}}$  and passed to the reverberators equally... [i]t should be noted, however, that if the reverberant signal were to be distributed equally to all channels for all apparent distances of the direct signal, at distances beyond the echo radius the reverberation would tend to mask the direct signal and eliminate the cue for angular location” (Chowning, 1977, 50). His solution is to have both a global reverb, sent to all speakers and a local reverb that emanates from the location of the direct signal. The global reverb would be further scaled by  $1/\textit{distance}$  and the local reverb would be scaled by  $1 - (1/\textit{distance})$ , so that the global reverb would fade out at large distances, and the local would fade in, “[t]hus with increasing distance of the apparent source, the reverberation becomes increasingly localized, compensating for the loss of direct signal energy” (50).

In my tests with the spatialization using reverb, I found that it wasn't always desirable artistically to model sounds in an enclosed space, and utilized the spatialization with reverb sparingly, only where the sound source warranted the reverb effect compositionally. So I made two versions of the spatializer one with and one

without reverb. As Chowning noted with “some percent of the direct signal”, the user still has control over how much of a reverberated signal is synthesized, using a common wet/dry parameter when apply sound effects. The spatializer without reverb is as if the wet/dry parameter was set to all “dry”, but without the added computer processing power needed.

---

### 2.2.5 Ambisonics

In section 2.2.1, a stereo panner based on delays was introduced. While we didn't look at a more traditional amplitude based panner, both create the the sound image, in this case stereo image, in one step; the decision as to where the sound might be, or what kind of stereo image to reproduce, immediately informs the signals sent to the loudspeakers. Ambisonics is a sound spatialization method that splits the panning law into two steps; encoding an ambisonic signal either captures or synthesizes a sound field using spherical harmonics, a set of mathematical equations to determine both the location of a sound in cartesian coordinates and the shape or type of the sound beam. Decoding an ambisonic signal determines the exact signals to send to a set of loudspeakers to (re)produce the desired sound field. Ambisonics is a deep field, however, and the depths of what ambisonics is and what it is capable of are outside the scope of this dissertation. There are a few final steps to the spatializer that take advantage of ambisonics.

The first is the shape of the spatialized wave-front. Since sound propagates like a sphere, sound sources that are near have curved wave-fronts when reaching the listener, and distance sound sources will have flat wavefronts, plane-waves. Using ambisonics, we can synthesize these various wavefronts.

The second is the size of the sound. If we think of a sound source as an actual sound object, as in *musique concrete*, we can also imagine that the sound has a size in sound space, and if we imagine a sound that is large when it is near, then the sound object would appear small when it is distant. This produces an effect similar to Chowning's idea of global and local reverb, but in the direct sound itself; when a large sound is near, it can occupy a large portion (or even all of the sound field and we can imagine we are inside the sound), similar to the global reverb, and as the sound moves away it becomes more localized in space, covering less of the sound field, similar to the global reverb.

To synthesize this technique, we can begin with a diffuse sound object, one that fills the entire space. Then, using ambisonics, we can beam form (or to use an analogy, place a virtual microphone with a pattern of our choosing, e.g. cardioid, hypercardioid, etc.) in the direction of where we want the sound to come from. Then we can crossfade between the diffuse sound and the sound beam to simulate the size of the sound object, or in other words, how much we "push" the entire sound field in one direction in space.

In SuperCollider, the Ambisonic Toolkit (ATK), developed by Dr. Joseph Anderson, was used to create the final version of the spatializer. For the wave front

shape, we use the near field control unit generator (UGEN) *NFCtrl*, which takes the sound radius location as the controllable parameter. Using *Hoazoom*, transforms the sound field by “zooming” in a particular direction using a cardioid beam pattern seen in Figure 15. Zoom takes a few arguments, distortion angle (shown as  $\alpha$  in Figure 15), theta, phi, radius, and order. For the spatializer, the input sound is assumed to be in encoded ambisonics (b-format) and the sound is either in the front (theta = 0, phi = 0)

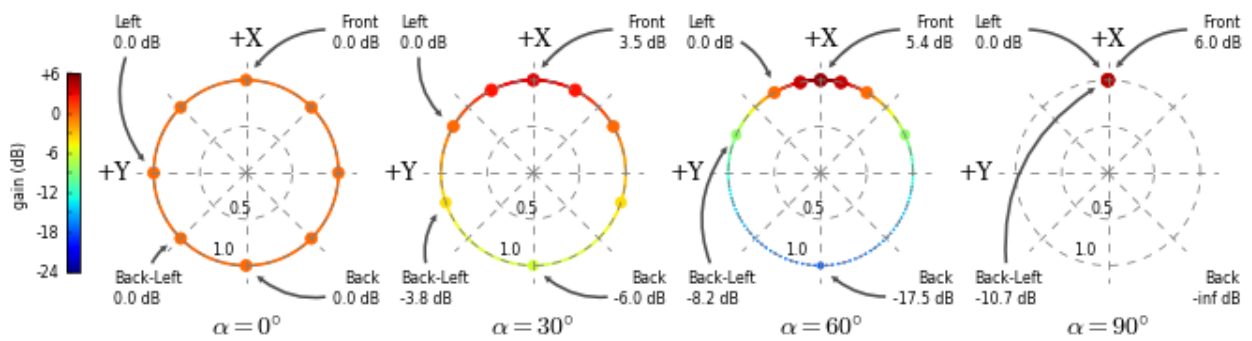


Figure 15. Visualization of the zoom transform. Ambisonic Toolkit Help Files for SuperCollider

or diffuse, the sound is everywhere. That way for the inputs to *Hoazoom* theta and phi are left at zero, i.e. we will be zooming in at the front and center of the sound field.

The distortion angle, the parameter that controls the balance between the cardioid virtual microphone and the original sound field, is set by the arctangent of the ratio of the distance of the sound object in meters to a user specified sound diameter. Thus, when the distance is large or the sound diameter is small, the distortion angle will approach 90 degrees, and conversely with a close sound that has a large diameter, the distortion angle will approach 0 degrees, shown in Figure 16. The columns represent different sound object diameters and the rows, the sound object distance from the

	100	10	1	0.1
100	45	84.3	89.4	89.9
10	5.7	45	84.3	89.4
1	0.57	5.7	45	84.3
0.1	0.057	0.57	5.7	45

Figure 16. Table showing the distortion angles in degrees for various distances and sound diameters.

listener. Given a diameter and distance, we can see what the resulting distortion angle would be.

Finally, we need to pan the object. The inputs to the spatializer are Cartesian coordinates. For ambisonics, these are converted to polar coordinates using the equations in Equation 3, where *rho* is the radial distance, *theta* is the horizontal angle and *phi* is the elevation. *atan2* is a special arctangent function that accounts for the correct quadrant. For instance, considering *theta*, when  $x > 0$ , *atan2* is equivalent to *atan(y/x)*. When  $x < 0$ , then depending on the value of *y*, the quadrant needs to be shifted by adding or subtracting  $\pi$ . In SuperCollider, these equations are implemented in the *Cartesian* class (in the *MathLib* quark). Since our sound is assumed to be at  $theta = 0$  and  $phi = 0$ , then we pan our sound to the desired location by first adding a tumble (rotation around the *y*-axis) and then a rotation (rotation around the *z*-axis), using *Hoatumble* and *Hoarotate* respectively.

$$\begin{aligned}
 rho &= \sqrt{x^2 + y^2 + z^2} \\
 theta &= atan2(y, x) \\
 phi &= atan2(z, \sqrt{x^2 + y^2})
 \end{aligned}$$

Equation 3

The full spatializer is shown in Figure 17. The user first inputs b-format ambisonic sound, followed by the desired x-y-z coordinates and a sound width in meters. The cartesian coordinates are converted to polar coordinates using the *Cartesian* class, which implements the math in Equation 3. The sound is then conditioned for distance and the doppler effect applied. Next the sound is given a size based on the distance and width using the math shown in Figure 16. The sound is tumbled and then rotated to complete the three-dimension panning. Lastly, the sound is given a near or far field shaped depending on the distance; the sound is first high-passed as a protective conditioning as the near field transform will boost low frequencies at proximate locations. The distance is also clipped to the minimum and maximum supplied by the user to further limit the proximity effects.

---

## 2.2.6 Spatializer with Reverb

Room reverberations provide further cues for the sense of distance as shown in sections 2.1 and 2.2.4. The reverb is added to then end of the code chain and scaled by a *mix* parameter in Figure 18. The reverb is also scaled by  $1/\sqrt{distance}$  from Chowning.

```

HoaSpatializer {
    *ar { arg in, x, y, z, width, maxDistance = 200, minDistance = 0.5,
order = AtkHoa.defaultOrder;
        var cart, amplitude, radialDistance;
        var phi, theta, chain;

        cart = Cartesian(x, y, z);

        theta = cart.theta;
        phi = cart.phi;
        radialDistance = cart.rho;

        // apply distance modeling for high freq absorption and
amplitude scaling
        chain = Distance.ar(in, radialDistance, minDistance,
maxDistance);

        // use a delay line based on the distance to simulate a doppler
shift
        chain = Doppler.ar(chain, radialDistance, maxDistance);

        // zoom in on the center of the sound-field based on the
arctangent of the distance and a user-defined width
        chain = HoaZoom.ar(chain, (radialDistance/width).atan, 0, 0,
AtkHoa.refRadius, order);

        // pan the sound using ambisonics
        chain = HoaRotate.ar(HoaTumble.ar(chain, phi, order), theta,
order);

        // prepare signal for near-field control
        chain = HPF.ar(HPF.ar(chain, 20), 20);

        chain = HoaNFCtrl.ar(chain, radialDistance.clip(minDistance,
maxDistance), AtkHoa.refRadius, order);

        ^chain
    }
}

```

Figure 17. Spatializer implemented in SuperCollider

```

HoaSpatializerReverb {
    *ar{ arg in, masterX, masterY, masterZ, width, revTimeHigh = 1.0,
revTimeLow = 1.0, maxDistance = 200, minDistance = 0.5, mix = 0.25, crossover
= 3000, order = AtkHoa.defaultOrder;
    var cart, amplitude, radialDistance;
    var phi, theta, chain, reverb, predelay, speedOfSound = 344;

    cart = Cartesian(masterX, masterY, masterZ);

    theta = cart.theta;
    phi = cart.phi;
    radialDistance = cart.rho;

    // calculate the predelay of the first reflection based on the
assumption it bounces off the floor, average human height 1.7m
    // minus the delay introduced by Doppler
    predelay = (((radialDistance/2).squared + 1.7.squared).sqrt * 2)/
speedOfSound - (radialDistance/speedOfSound);

    // apply distance modeling for high freq absorption and amplitude
scaling
    chain = Distance.ar(in, radialDistance, minDistance, maxDistance);

    // use a delay line based on the distance to simulate a doppler
shift
    chain = Doppler.ar(chain, radialDistance, maxDistance);

    // zoom in on the center of the sound-field based on the
arctangent of the distance and a user-defined width
    chain = HoaZoom.ar(chain, (radialDistance/width).atan, 0, 0,
AtkHoa.refRadius, order);

    // pan the sound using ambisonics
    chain = HoaRotate.ar(HoaTumble.ar(chain, phi, order), theta,
order);

    // prepare signal for near-field control
    chain = HPF.ar(HPF.ar(chain, 20), 20);

    chain = HoaNFCtrl.ar(chain, radialDistance.clip(minDistance,
maxDistance), AtkHoa.refRadius, order);

    reverb = HoaReverb.ar(chain * mix *
radialDistance.clip(minDistance, maxDistance).reciprocal.sqrt, 1.0, predelay,
crossover, t60high: revTimeHigh, t60low: revTimeLow);

    ^chain + reverb
}
}

```

Figure 18. Spatializer with Reverb

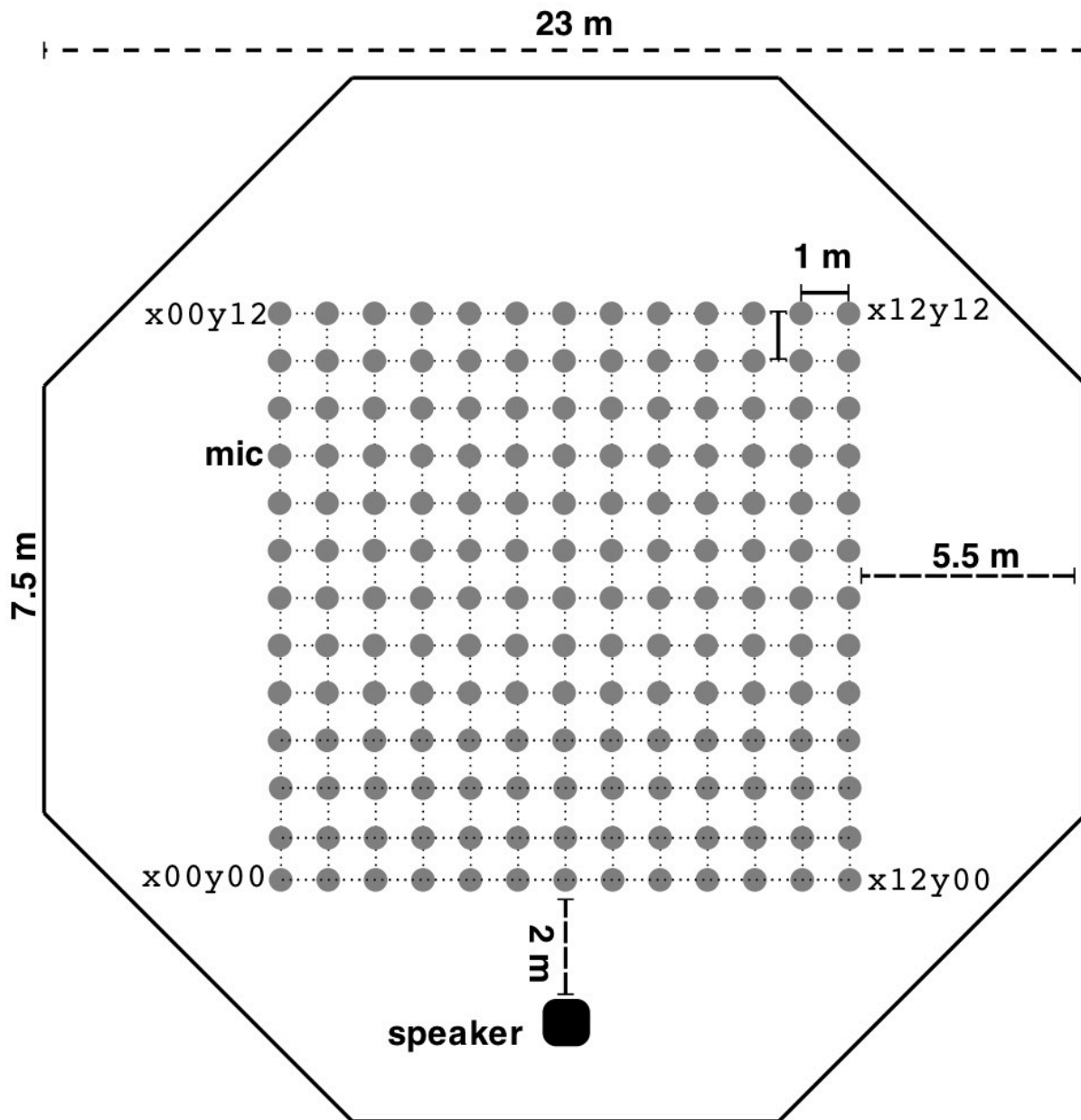


Figure 19. Diagram of RIRs. <http://isophonics.net/content/room-impulse-response-data-set>

## 2.3 Room Impulse Responses

The above spatializer models a virtual space, simulating “generic” conditions. For the spatializer without reverb, this space could be an open-aired field, with no surfaces off of which the sound can reflect. The spatializer with reverb models a non-

specific medium sized room. Using room impulse responses (RIRs), a specific room or concert hall can be measured and then modeled. In 2008, Rebecca Stewart and Mark Sandler published a collection of room impulse responses measured at Queen Mary, University of London. The measurements were taken with two microphones, an omnidirectional and a sound field microphone encoded into b-format.<sup>4</sup> For the spatializer, I utilized the b-format measurements, upsampling them to 3rd order ambisonics using the Harpex upsampler.<sup>5</sup> The various measurements were taken on a grid of equal spacing shown in Figure 19. Using the measurement involves convolving a desired sound with the impulse response. The result should be that the desired sound now sounds like it would if it were being played on the speaker and the listener is seated at the spot of the measurement chosen. The sound should be as if it were in the particular room. Crossfading between convolved sounds with different measurement locations would make the sound move between those locations.

For the spatializer, I chose to work with just the center locations on the grid, those that are directly in front of the speaker. Crossfading between these locations would simply move the sound closer or farther away. The panning can then be left to the ambisonic panner. In SuperCollider, the UGEN *SelectX* will perform equal power panning between audio signals. The sound input is simultaneously convolved with all 13 of the center impulse responses, and then *SelectX* crossfades between them depending on the distance desired while an ambisonic panner is used to move that

---

<sup>4</sup> *Room impulse response data set*. Isophonics. (2008). <http://isophonics.net/content/room-impulse-response-data-set>

<sup>5</sup> Harpex. (n.d.). <https://harpex.net/>

```

HoaDistRIR3 {
  // mono input, assumes 3rd order IRs
  *ar { arg in, partConvBuffers, fftsize, rho, theta, phi,
order = AtkHoa.defaultOrder;
  rho = rho.clip(1, 13);
  in = partConvBuffers.collect{ |bufs|
    bufs.collect{ |buffer, i|
      PartConv.ar(in, fftsize, buffer)
    }
  };
  // select which radius of convolution
  in = SelectX.ar(rho - 1, in);
  // tumble to phi
  in = HoaTumble.ar(in, phi, order);
  // rotate to theta
  in = HoaRotate.ar(in, theta, order);
  ^in
}
}

```

Figure 20. RIR Convolution implementation in SuperCollider

sound in space, shown in Figure 20. In SuperCollider, the impulse responses are too long for a single convolution kernel, so this has been implemented using *PartConv*, a tool that splits the convolution kernel into smaller chunks and mixes them back together. The preparing of the kernels and loading them into buffers is shown in Figure 22.

The impulse responses contain the direct signal and the late and early reflections (the reverb). The direct signal can be removed via a waveform editor, which leaves just the reverb. The impulse response can then be used as a reverb replacement for the spatializer in Figure 18, shown in Figure 21. The direct signal that was removed from the RIR is now synthesized with the spatializer.

```

HoaSpatializerRIR {
    *ar{ arg in, masterX, masterY, masterZ, width, partConvBuffers,
fftsize, maxDistance = 200, minDistance = 0.5, mix = 0.25, order =
AtkHoa.defaultOrder;
    var cart, radialDistance;
    var phi, theta, chain, reverb;

    cart = Cartesian(masterX, masterY, masterZ);

    theta = cart.theta;
    phi = cart.phi;
    radialDistance = cart.rho;

    // apply distance modeling for high freq absorption and
amplitude scaling
    chain = Distance.ar(in, radialDistance, minDistance,
maxDistance);

    // use a delay line based on the distance to simulate a
doppler shift
    chain = Doppler.ar(chain, radialDistance, maxDistance);

    // zoom in on the center of the sound-field based on the
arctangent of the distance and a user-defined width
    chain = HoaZoom.ar(chain, (radialDistance/width).atan, 0, 0,
AtkHoa.refRadius, order);

    // pan the sound using ambisonics
    chain = HoaRotate.ar(HoaTumble.ar(chain, phi, order), theta,
order);

    // prepare signal for near-field control
    chain = HPF.ar(HPF.ar(chain, 20), 20);

    chain = HoaNFCtrl.ar(chain, radialDistance.clip(minDistance,
maxDistance), AtkHoa.refRadius, order);

    // use impulse responses for reverb
    reverb = HoaDistRIR3.ar(chain[0] * mix *
radialDistance.clip(minDistance, maxDistance).reciprocal.sqrt,
partConvBuffers, fftsize, radialDistance, 0, 0, order);

    ^chain + reverb
}
}

```

Figure 21. Spatializer with RIR Reverb

```

HoaRIR {
  var <type, <fftSize, reflection, server;
  var <bufferDict, numChannels, <gridPoints, <irBuffers, <bufSizes,
<delay;
  var <irbuffers, <irspectrums, <rirPath, order;

  classvar <>rirDir;

  *initClass {
    rirDir =
File.realpath(HoaRIR.filenameSymbol.asString.dirname.dirname ++ "/"
Impulse_Responses");
  }

  *new { |type = 'GreatHall', fftSize = 2048, reflection = true, server|
    ^super.newCopyArgs(type, fftSize, reflection, server).init
  }

  init {
    rirPath = (type == 'Octagon').if({
      PathName(rirDir ++ "Octagon");
    }, {
      PathName(rirDir ++ "GreatHall")
    });

    rirPath = reflection.if({
Reflection_48000/"
    }, {
      rirPath ++ PathName("HOA3_ACN_N3D_NFDist/RAW_48000/")
    });

    // set part delay size
    server = server ?? { Server.default };
    delay = fftSize / 2 - server.options.blockSize;

    order = 3;

    numChannels = order.asHoaOrder.size;

    irbuffers = rirPath.files.collect{ |pathname|
      numChannels.collect{arg i; CtkBuffer(pathname.fullPath,
channels: i)}
    };

    bufSizes = irbuffers.collect{ |pointBuffers|
      pointBuffers.collect{ |irbuffer|
        PartConv.calcBufSize(fftSize, irbuffer)
      };
    };
  };
}

```

```

        irspectrums = bufSizes.collect{ |pointSizes|
            pointSizes.collect{ |bufSize|
                CtkBuffer.buffer(bufSize, 1)
            }
        };

        irspectrums.do{ |pointspectrums, i|
            pointspectrums.do{ |irspectrum, k|
                irspectrum.preparePartConv(0.0, irbuffers[i][k],
fftSize);
            }
        };

    }

    addTo { |score|

        irspectrums.do{ |pointBuffers|
            pointBuffers.do{ |buffer|
                buffer.addTo(score)
            }
        };

        irbuffers.do{ |pointBuffers|
            pointBuffers.do{ |buffer|
                buffer.addTo(score)
            }
        }
    }
}

```

Figure 22. Loading and preparation of impulses in SuperCollider

---

## 2.4 Flock

In 1986, Craig Reynolds developed an artificial life program, *Boids*, which simulates flocking behavior using three forces that act upon each member of the flock: cohesion, alignment, and separation; cohesion steers each member of the flock toward one another, alignment steers each member toward the average direction of the flock and separation steers each member away from other surrounding members.

In *The Nature of Code*, Daniel Shiffman presents an algorithm in Processing, a visual programming language, to simulate the motion of the flock. In Shiffman's version, the members of the flock are represented by triangles moving on the screen, and as they reach the edge, they simply wrap around and appear on the opposite side of



Figure 23. Daniel Shiffman's flock from chapter 6 of *The Nature of Code*

the screen. For my version in SuperCollider, the members are represented by sounds in 3D ambisonic space. Since there is no physical screen edge in a sound environment, flock members theoretically can move infinitely in any one direction, but when modeling for distance, as their amplitude decreases with respect to distance, at a far enough distance would be inaudible. To keep flock members always coming back I introduced a fourth force, usually placed at the center, that would act like gravity in space and always bring the members back. To make sure they always come back, I made this force inversely proportional to distance; the farther away they get, the more of this central force they feel, and the closer they get, they feel less of this force, so that they are able to fly by and not get stuck.

## III. Vanishing Portals

---

### 3.0 Introduction

This chapter describes some of the artistic inspiration behind various sections of *Vanishing Portals*. The composition process is often made up of a series of choices and problems to be solved. Some of these decisions are documented here along with technical explanations as to how they were realized. Interwoven into this section are various inspirations from other pieces as well as pieces of my own. *Vanishing Portals* represents much of what I had been thinking about and working on during my doctoral studies.

---

### 3.1 The Garden of Earthly Delights

The original inspiration for *Vanishing Portals*, and where the title is derived, comes from the triptych oil painting, *The Garden of Earthly Delights*, by Hieronymus Bosch. The three-panel work depicts eden on the left, earth in the center, and hell to the right. The center scene, the garden of earthly delights, depicts naked humans acting with free will, dancing, riding various animals, eating and other indulgent activities. There are also fantastical structures, especially toward the top of the frame, placed in a symmetrical arrangement. Each of these structures, including some of the smaller ones toward the bottom, have entry points at their base, where people can be seen either entering or exiting. There are similar structures on both eden and hell, and



Figure 24. The Garden of Earthly Delights

I imagined that these might be connected, and that maybe these could be the entry/exit points, or portals, that connect the three worlds. The idea of composing sonic portals combined with my compositions of sound worlds and the inspiration from Grisey's *Le Noire de l'Etoile*, which uses the spinning of pulsars to dictate rhythms, I imagined a piece of extraterrestrial sound worlds, and the transitions between each would be the portals that vanish and don't allow you to travel back, just as time moves forward only. Each sound world has a different structure and feel and so the piece is a journey through space-time.

---

### 3.2 Recording as Composition

*Vanishing Portals* is a 3D music composition for fixed media. All the sounds are either recorded or synthesized, processed using SuperCollider (SC), an audio



Figure 25. Eigenmike courtesy mh acoustics

programming language, and sequenced, composed and mixed using Reaper. Some sounds were recorded using an Eigenmike and converted to third order ambisonics. Others were recorded with a Soundfield mic, and others with a pair of binaural (in-ear) microphones.

In 2015, I composed a piece, *Steilacoom*, for ambisonic soundtrack. The piece centers around the sounds and spatial movements of a real train and of a synthesized train using recordings of percussion instruments. The train was recorded with a 3D sound field microphone and the piece begins with a train approaching from the right and passing by to the left. While immersed in the sound of the real train, a synthesized version of this exact train, using drums to mimic the “clickety-clack” of the train and filtered white noise to make the wind/brake sounds, slowly replaces the train. As the synthesized train fully takes over, the train makes a circle around the sound field instead of passing only left to right, and eventually the real train comes back to finish the opening section. Later in the piece, there are train squeaky sounds that morph via

layering and pitch shifting into a sort of orchestral sound. The drums that mimicked train in the open section return to accompany these orchestral “squeaks”, except their rhythm more closely resembles a drum roll, with the train “speeding up” and “slowing down” virtually. In *Steilacoom*, the drum recordings were single hits, i.e. there is no rhythmic or gestural material. The rhythmic roll structure was created using algorithms. In contrast, the composition process for *Vanishing Portals* started in the recording of drums.

In the summer of 1981, acousmatic composer, Jonty Harrison, recorded two casserole dishes, that he found in the home of Denis Smalley, for his piece *Klang*. Harrison recorded a few gestures banging the dishes together, tapping the lids on the bowls and also running the lids inside the bowls to produce a continuous rolling sound. In this way, the composition for *Klang* had already started with setting these various attacks/textures down on tape, giving material that already has a timbral and temporal shape that can then be altered and layered together in the studio. Thus, in the recording process, Harrison has already made compositional choices including the gestural rhythm of the banging of the dishes and the textural and spectral aspects of the continuous rolling sounds.

In *Vanishing Portals*, I wanted to revisit the drum roll from *Steilacoom* but as a central theme. While percussive rolls come in various shapes, I was inspired by the use of the roll in Gérard Grisey’s *Le Noire de l’Etoile*. In the piece, there are six percussionists who surround the audience. Inspired by the rhythm of pulsars, rotating neutron stars, Grisey uses carefully timed rolls (and other gestures) between players to

simulate sound moving around the space. These movements accelerate and decelerate mimicking the pulsars and also the structure of the roll, which starts out slow and quiet, accelerates to a crescendo, then slows again and decrescendos. This simple structure is the DNA for *Vanishing Portals*. I call this “up, down, up” (UDU), even though the structure is often inverted, as in the drum roll, to “down, up, down”.

In the summer of 2018, I recorded a few drum rolls using the Eigenmike, a spherical microphone with 32 capsules, with the help of fellow student James Wenlock. The recordings were then converted to 3rd order ambisonics, and processed with the Ambisonic Toolkit and SuperCollider. The processing involved fixing the spatial aliasing at high frequencies and final equalizing frequencies. The resulting recordings have the drum roll spatialized in the front. These drum rolls form the opening of the piece. I wrote an algorithm in SuperCollider that slowly adds more and more drum rolls to eventually create a texture. Before this texture is reached, the rolls are successively pitched shifted up one semitone and then back down again, mirroring the structure of the roll itself, an inverted UDU. The original gesture of the recorded roll provides the pacing and rhythmic structure for this opening section.

As more and more rolls are added via the algorithm, they are panned to different spots in space. They start in the front and slowly spread across the sound field. One effect of this is that the listener becomes enveloped in the drum roll sound. The other is that when the pseudo-random timing of the rolls line up in a certain way, it can sound like the drum roll moves in space, even though each drum is statically

panned, as happens in *Le Noire de L'Etoile*. The random nature of the algorithm is such that this is not meant to happen all the time and should be an ephemeral effect.

---

### 3.3 Feedback

Feedback is a common audio signal processing technique (it is also a strange loop!). It is used in various effects e.g. echo, flangers, chorus, comb filters, etc.

Feedback itself can be an effect. In fact, the drum roll itself is sort of a feedback as the player strikes the drum quickly so that the previous sound has not finished before the next one begins; at certain speeds of playing, the sound evolves from a percussive attack sound to a textural one. Figure 26 below is a simple feedback loop. In this case it represents a comb filter, but it can be used in ways that doesn't produce the combing

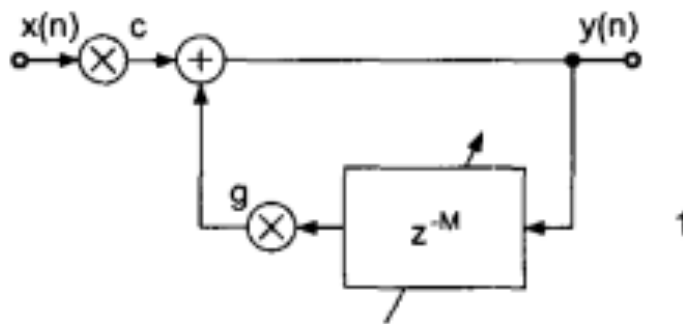


Figure 26. Zölzer *DAFX* p. 65

effect. The sound comes in at  $x(n)$  and goes out at  $y(n)$ . In between the sound is feed back onto itself with an effect and a gain. In this case the effect is a delay. The higher the gain, the more feedback occurs.

```

FeedbackFreqShift {
    *ar { arg in, delayTime, rt60, freqShift, maxDelayTime = 1.0,
numChannels = HoaOrder.new(AtkHoa.defaultOrder).size;
    var localIn, gain;
    var ssbSig;

    gain = rt60.rt60toG(delayTime);

    localIn = LocalIn.ar(numChannels) * gain;

    ssbSig = FreqShift.ar(in + localIn, freqShift);

    ssbSig = DelayC.ar(ssbSig, maxDelayTime, delayTime);

    LocalOut.ar(ssbSig);

    ^ssbSig
    }
}

```

Figure 27. Feedback Frequency Shifter in SuperCollider

For *Vanishing Portals*, I used a similar feedback loop with a frequency shifter, delay, and gain in the feedback loop, seen in Figure 27. I also used a similar feedback frequency shifter called ValhallaFreqEcho by Valhalla DSP. ValhallaFreqEcho has

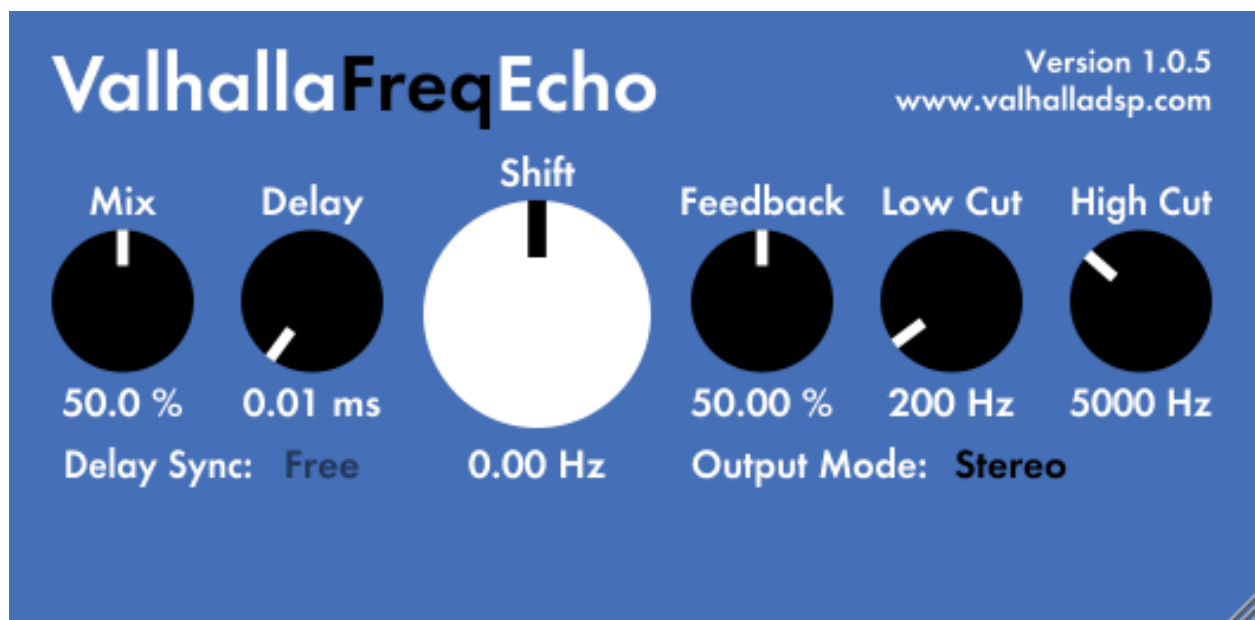


Figure 28. Valhalla DSP FreqEcho

lowpass and highpass filters, as well as some sort of limiting to allow the feedback to get to 100% without blowing up. The section following the drums is mostly filled with sounds synthesized or processed using one of these feedback loops.

The first set of sounds were created by feeding a single impulse into the feedback frequency shifter with a large enough delay time to provide an echo effect. The result is a synthetic percussive sound most clearly heard in the section from 9:00-11:20. This sound has been processed, sent through feedback loops again, pitch shifted and layered to comprise about 90% of the sounds from 6:00-12:00. A second set of sounds were created with the sound of bowing on a cymbal, courtesy of the University of Iowa Electronic Music Studios musical instrument samples, fed into the feedback loop. These sounds are most clearly heard around 14:00-15:00. The sounds are particularly interesting to me because of the frequency shifting that creates an homage to the Shepard tone used by Jean-Claude Risset in *Mutations*. While these sounds were not meant to exactly mimic the Shepard tone, specifically the trick of “hiding” the fading in of the lower octaves and the sound continually rises, they use the essence of an ever rising tone with the feedback into a frequency shifter that shifts up.

---

### 3.4 Recording as Composition, A Return

In 2018, I composed a piece, *The Misweaves*, for flute, cello, harpsichord and digital sound. For the computer composed part of the piece, I recorded each of the

three instruments playing various notes and gestures that were already in the acoustic part of the piece. These recordings would accompany the acoustic trio and also guide them through the timing of the piece. For *Vanishing Portals*, I revisited these recordings and combined them in new ways not heard in *The Misweaves*.

The first set of recordings I used were single notes on the flute, A-flat and C, making a third, the first two notes of a triad in A-flat major. I processed these recordings with the same algorithm as the drum rolls in the first section including the pitch shifting up one semitone to provide an inverted UDU. I then layered a few of these at different starting pitches and spread them in time. The next set of recordings were flute whistles, where the flute whistles at the mouth piece without resonating the body of the flute. These sounds were played back at various lower octave rates (0.5 and 0.25) and layered in same way as John Oswald's *Bell Speeds*.

For the ending of this section and transition to the final section, I recorded my late grandfather's accordion. I recorded various notes and gestures but decided to use a trill, in keeping with the the theme of up, down, up, or down, up, down, up, etc. These trills were layered in similar ways to the flute and the drums, to create a texture similar to the drum roll and spatialized with the flocking algorithm.

---

### 3.5 Spatialization as Down, Up, Down

In 2017, for my general exam, I composed a piece for ambisonic soundtrack, *Spun-Glass Garden*. For the exam, I was instructed to read *Zero K* by Don DeLillo and

construct, in 3D music, hallways and corridors, analog to those that exist in DeLillo's novel. Much of the novel takes place in a sort of futuristic hospice facility where the rich or privileged go to have their bodies frozen and preserved to escape the turmoils of the present day in hopes that one day far in the future, their bodies can be restored by the advances of science and all their ails and aging can be cured. The facility is ominous and strange with empty hallways filled with closed doors, behind which we never see. Some hallways, however, have videos projected onto the far wall with scenes that depict the tumultuous present state of the world, e.g., scenes of war, meant to remind the patients why they are there and what they are escaping. Other hallways are filled with various works of art, and behind one door is an ultra-realistic garden entirely made of glass. While composing a piece not only meant to derive inspiration from but to attempt to construct these various hallways, I realized that our labs at DXARTS mirror the facility in *Zero K*. Our hallways are lined with closed doors, some contain art, others do not. Participating in a rigorous doctoral program can feel like you are dying or in need of care and sometimes while making art one can feel disconnected from the outside world. The analogy isn't perfect, but what I decided was that *Spun-Glass Garden*, while mostly exploring themes from *Zero K*, obviously the hallways and corridors, but also death, relationships with family, specifically between father and son, mentor and mentee, was also a chance for reflection on life at DXARTS and a meta-representation of the piece itself.

While composing the piece in the DXARTS sound lab, I decided to record parts of the piece from our own hallway, behind both closed and open doors, as if someone

were walking down the hallway and hearing music being composed. These recordings were then composed into the piece as a sort of self-reference, and also to provide a new spectral and spatial perspective on the sounds. In addition, I used sound spatialization to synthetically create the sense of moving past these sounds. The experience of the piece, however, is the listener is sitting still and the sounds are moving past.

In *Vanishing Portals*, I revisited this technique of sound spatialization. With sounds moving closer and farther away from the listener we have encountered another iteration of the inverted UDU; the sound starts far away and is quiet, then moves closer and gets louder until it passes by and then gets quieter and quieter, the drum roll. If we include the Doppler shift, then we also get the inverted UDU in terms of pitch; the pitch rises as the sound object gets closer, and then lowers as the object moves away.

There are two distinct modes of this spatialization in *Vanishing Portals*. The first comes from John Chowning's *Turenas*, where he spatialized certain sounds following the path of a Lissajous figure, created from a set of parametric equations, shown in Figure 29. Chowning's Lissajous plot is shown for values of  $t$  from 0 to 1 using Equation 1. In *Vanishing Portals*, values of  $t$  were from 0 to the total duration of the sound. As  $t$  moves past 1, the shape Lissajous continues its path as shown in Figure 31. Values of  $t$  greater than 2, the Lissajous figure repeats just as a circle repeats after  $2\pi$ , shown in Figure 32. The sound continually goes along this path as long as the sound is active.

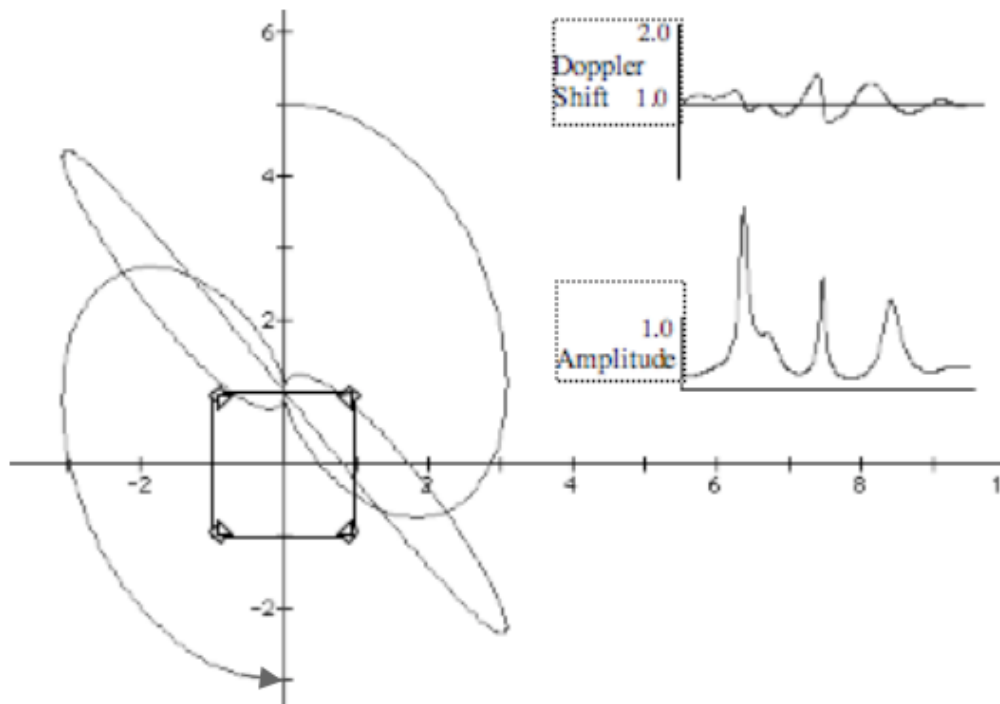


Figure 29. John Chowning's Lissajous figure from *Turenas: the realization of a dream*

$$x = \sin 2\pi t + \sin 6\pi t$$

$$y = \cos 3\pi t + \cos 7\pi t$$

Equation 4

The second mode of spatialization mimics the path a flock of birds or fish might take. In 2017 I composed, *Alignment, Cohesion, Separation: A Flocking Study* (ACS), that uses the flocking algorithm both as a spatializer and also as a composer. ACS is also a continuation of research started in 2015 with *Container Study* where sounds are algorithmically searched for on a community database of recorded sounds, Freesound.org. There are two main groups of sounds, having to do with travel, cars, trains, etc. and bird sounds. For each group, the sounds are organized into a virtual spatial map based on their spectral similarities, specifically, sounds are given a cartesian coordinate. A third sound map was created by placing each note from the

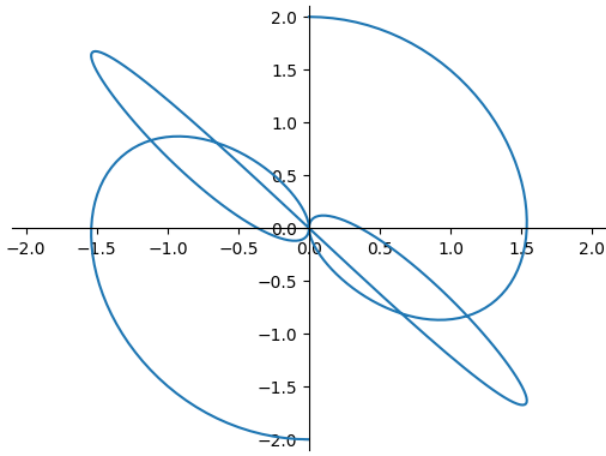


Figure 30. Chowning's Lissajous  $0 \leq t \leq 1$

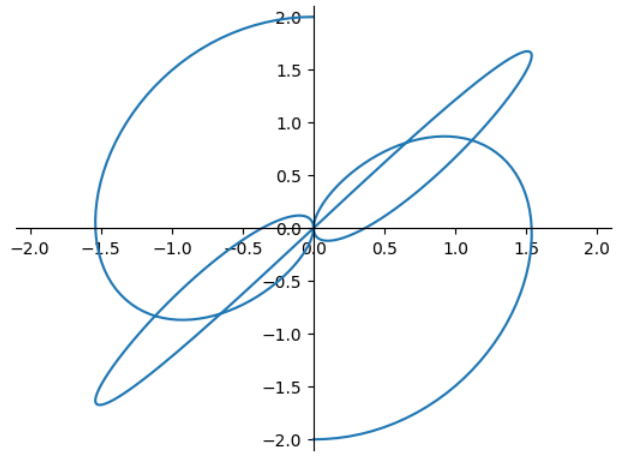


Figure 31. Chowning's Lissajous  $1 \leq t \leq 2$

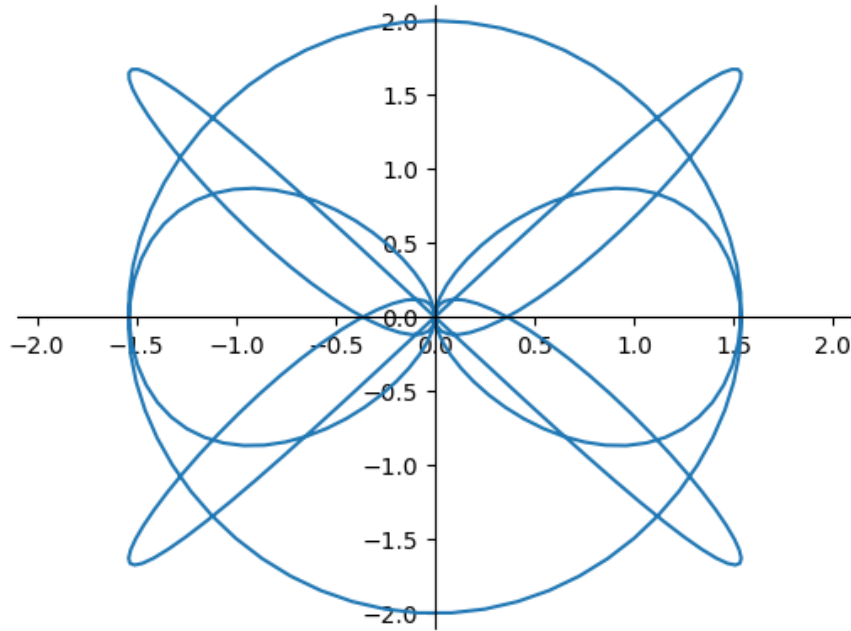


Figure 32. Chowning's Lissajous  $0 \leq t \leq 2$

first movement of Beethoven's 9th Symphony in space with the x-axis representing time and the y-axis representing the different instruments. The instrument samples for the University of Iowa comprise this sound map.

Once the map is created, the flock "flies" through this virtual space. When a member of the flock moves within a specified distance of one of the sounds, that sound is triggered. In this way, the flock controls the timing and rhythm of each

sound. There are two modes for the flock playing the sound. When a sound is played by a flock member, that same sound cannot be played again until that member plays a different sound. The second is that the sound can be triggered indefinitely by any flock member as long as the member is within the minimum distance. When this second mode is active, the sounds are triggered at the frame rate that the flock's positions are updated, resulting in a sort of feedback-like texture.

The sound map is also expanding and contracting as the flock interacts with it. This affects the density of the sound; while the sound map is spread out and sparse, the chance of a flock member triggering a sound is reduced, and conversely with a dense map, the flock plays many (or sometimes even all) of the sounds in the map all at once. Each sound in the map is also spatialized based on its x-y coordinates.

In *Vanishing Portals*, flocking is used solely for spatialization. For clarity of space, I used only one sound per flock. The sound is spatialized as if it were at the center of the flock and the central force for the flock is the center of of the space at the ideal listening spot. The flock flies around the sound field, similar to the Chowning Lissajous, but with the timing and cadence of a flock. The Lissajous sound path occurs at the end of the drumming section around 4:00-5:00. The drums that were once stationary in space, begin to be introduced in the Chowning Lissajous pattern. The flocking sound spatialization happens throughout the piece, but most notably during the accordion section just before the final section and all throughout the final section.

---

### 3.6 The Portals Return

In *Spun-Glass Garden*, the piece folds back upon itself; the piece contains part of the process of creating the piece. *Vanishing Portals* ends in a similar way, with all the previous sounds in the piece flying in and out via the flocking algorithm. The piece is self-referential in this way, and provides a new perspective on these sounds.

The final section is marked by a single hit of a drum. This drum hit calls the sounds from the previous portals to come back, acting as a sort of portal for their return. Each sound that returns is spatialized with the flock, swarming and orbiting this central drum sound. The drum sound itself crescendos and also is joined by a synthesized electronic drum and the low attack sound from the second part of the first section. As the final section reaches its climax, more and more sounds from the first section are added until the feedback delay frequency shifter sound returns to overtake the scene and one final drum hit ends the piece.

---

### 3.7 The Structure of *Vanishing Portals*

*Vanishing Portals*' macro structure is like *The Garden of Earthly Delights* in that it has three parts, earth, Eden, and hell. This macro structure embodies the structure of the UDU, with Eden being the peaceful, quieter "down". The UDU and

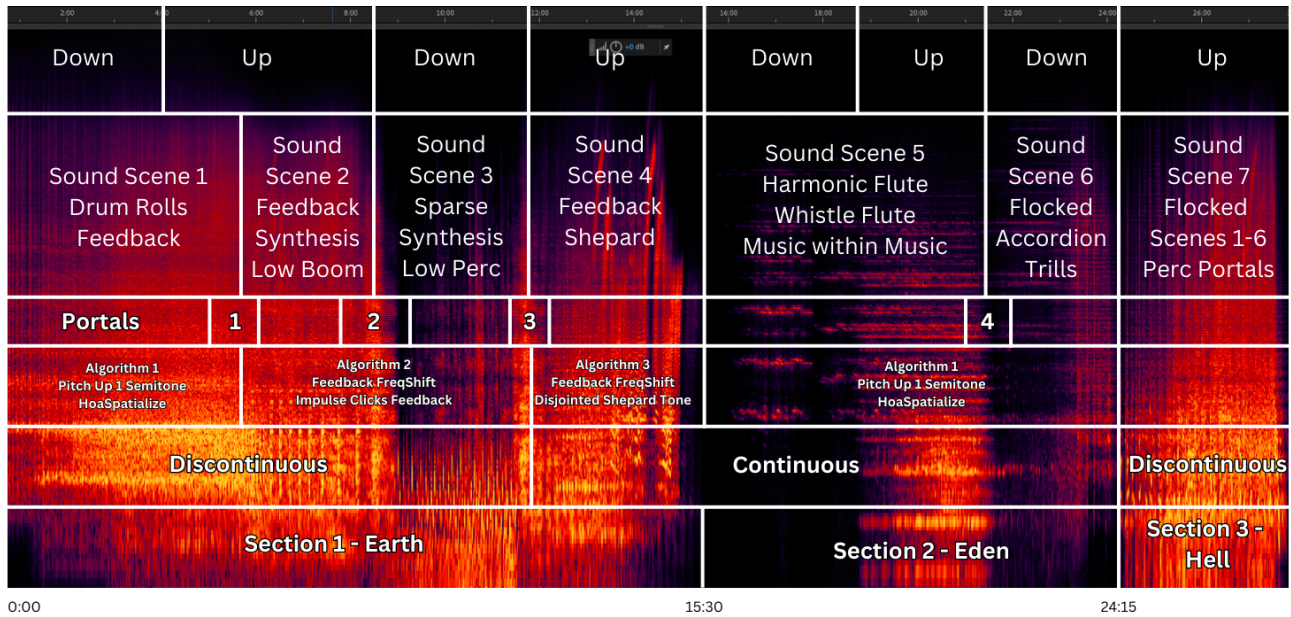


Figure 33. *Vanishing Portals* Structure

inverted UDU, as the DNA of the piece, is present on every level. The dynamics of the piece is DUDUDUDU, as shown in the top line of Figure 33, which is found in the second level structure of each sound world. Within each sound world, there are semitone pitch shifts which is the inverted UDU, and the micro composition of the sound gestures, such as the drum roll, the accordion trill, and the sound spatialization are also the inverted UDU.

Additionally there is an overall trajectory of discontinuous to continuous sounds, similar to Risset's *Mutations*. The beginning third of the piece consists of sounds with sharp attacks, the drum roll and the impulse feedback synthesis. This transitions to continuous sweeping sounds for the middle third of the piece, including the bowed cymbal with feedback and the flute notes and whistles. The discontinuous returns, to complete the strange loop, with the accordion trill and the ending section with drums. Discontinuous-continuous-discontinuous, up-down-up.

The first section contains four sound worlds with three transitions (portals). The first sound world consist of only the drum roll, in this case a floor tom. The roll is played with no processing in the beginning of the piece. As it repeats, it is pitch shifted up one semitone and back down again. As more and more drum rolls are introduced, a processed version of the roll through the feedback frequency shifter enters. Toward the end of the first sound world, the drum rolls are then spatialized using *Hoaspatializer* with the Chowning Lissajous trajectory. The first portal happens when the feedback sound takes over and a low bass rumble (with a flanger effect) begins at regular intervals. This signals the second sound world which is comprised of three layers, the first being the low rumble. The second two are various iterations of the single impulse fed into the feedback frequency shifter, with the shift negative so the pitch goes down. In one layer, this impulse synthesized sound is layered in the same way as the drums from sound world one. The second layer, the impulse sound is spatialized using the flocking algorithm, coming in and out as it travels near and far. The second portal is a cacophony of these impulse feedback sounds, which ends the second sound world.

The third sound world is a sparse low synthesized drum hit. Again this sound is sequenced using the beginning drum roll algorithm, except that it is also pitched down randomly at one and two octaves below. The flocking impulse from sound world two continues but in a much more sparse way. The fourth world, introduced in the same way as the second portal, the same portal, but leads to a different world, begins the continuous portion of the piece. The first sounds are flanging and fading in and out

processed fog horn sounds from my first DXARTS piece, *Container Study*. The second set of sounds are the Shepard like rising tones created by processing the bowed cymbals from the University of Iowa Electronic Music Studios musical instrument samples with the feedback frequency shifter, with the shift being positive. This sound ends section one.

The second section has two sound worlds. The first are the layered harmonic flute recordings from *The Misweaves*. The flute sounds were layered like the opening drums with an occasional pitch shift up of one semitone. As these continue, the flute whistles enter, layered in octaves and spaced in time like Oswald's *Bell Speeds*. These whistles also act as the fourth and final portal which leads to the accordion trills. The trills have been layered in octaves and fly around the space using the flocking algorithm, and is the start of the final discontinuous sound section.

The last section is a chaotic representation of the sound worlds that came before, although we never return specifically to them as they swarm and fly by as described in 3.6 and similar to the idea in *Spun-Glass Garden*; the return and repetition of sounds from the previous sound worlds is the self-reference, the main strange loop of the piece. The last section is marked by a loud single drum hit. The accordion trills from the previous section continue but seem to be trying to avoid the drum hit in time and space. As the section progresses, sounds from worlds 1-4 are introduced as if the drum hit has conjured them back into existence, until all sounds have come back and are flying around like a flock of galaxies. After this section was composed, it was itself processed with the feedback frequency shifter. The

unprocessed version and the feedback version were then mixed back together and as the section builds, the feedback version takes over until it is all that is left at the end of the piece.

---

### 3.8 Future Work

The beginning stages of composing *Vanishing Portals* consisted of experimentation in the lab. I had various sequencing algorithms, digital sound processing techniques, and sound spatialization ideas, some of which I had been working on for years and were used in previous pieces as discussed above, but which hadn't been combined into a single process. I took various recordings, some not discussed here, and fed them into these processes, sometimes taking the results and feeding them back into the same process. I set up a master algorithm to automate this process using dozens of combinations of the different types of processing: temporal, spectral, and spatial. Each sound process was fed back into the same process again three times successively. The result is terabytes worth of different sounds that are categorized and documented using version control (git). Likely more than 90% of these sounds never made it into *Vanishing Portals*. In fact, the first version of *Vanishing Portals* performed at Meany Theater at the University of Washington in 2019 sounds almost nothing like the final version. In my view, there is only one *Vanishing Portals*, the final version, as I do not see each iteration as a revision, but

each performance is part of the compositional process of discovering what works, what the problems are, and how to fix them.

In some ways, *Vanishing Portals* represents the culmination of a particular aesthetic that started with my masters thesis *Swarm of Echoes* and continued through *Container Study*, *Steilacoom*, and *Spun-Glass Garden*. While some of the material created in the early part of the compositional process will be used in future pieces that have nothing to do with *Vanishing Portals*, I do plan to compose a sequel to *Vanishing Portals* as not only is there a lot of similar material that I would like to work with, there is an entire composed sound world that I decided not to include in the final version of the piece, both for aesthetic and durational reasons (this section was made with recordings of baby toys belonging my newly, at the time, born daughter).

In addition to aesthetic pursuits, there is much work to be done with my spatializer. There are other distance cues, pioneered again by John Chowning, that I would like to work into the current version. The impulse response spatializer also needs improvement, both in computational efficiency and concerning the spectral qualities introduced by the impulse response itself.

---

### 3.9 Why Music?

Physicist Richard Feynman once went on a famous rant when asked by an interviewer why two magnets repel each other. He argued that the ‘why question’ is very difficult as it can lead to an endless series of other ‘why questions’. ‘Why

questions' are indeed difficult to answer, but as a composer, I can't help but wonder why I even compose music? Do I just like it? Or because I have always had a deep fascination for sound? Or do I particularly only enjoy music and not all sound? Over many years of periodically pondering this question, I have found the reason I compose might be to answer a few other difficult 'why questions': why do I like a particular piece of music and not another, and why do I like a particular sound and not another? I compose music to explore why I like other music. What is good about them? What are their structures or forms that evoke sublime emotions in me when I listen to them? Why do I like certain sounds and am repelled by others? What properties of these sounds give them meaning and how can I use these properties in my own music? I compose music with recorded and synthesized sounds to explore what is attractive about these sounds and their properties. One of these properties that I feel has much fertile ground to be explored is space.

To close off the strange loop of this dissertation, I will return to the beginning, to Achilles and the Tortoise. The paradox ponders the impossibility of motion through space. We can extend this idea to any activity, even thinking itself. If the neurons in our brains cannot fire, the electrical and chemical signals they produce cannot "move" to the next neuron and communicate, then we cannot even think. If humans can do anything, it proves this paradox incorrect, or more miraculously solved by the fact that we can traverse infinities. If I compose music, it is to prove simply that I can do something, that I can traverse infinity and that, more importantly, I know something and can think, and that I can communicate that to the world. I can play the scales.

## Bibliography

- Altomare, F. C. (2013). *A calculus of fire: Strange loops and autopoietic consciousness in selected twentieth-century fiction from James Joyce to Philip K. Dick—A cognitive poetic approach*. ProQuæst Dissertations Publishing.
- Anderson, Joseph L. *Ambisonic Toolkit*. <https://www.ambisonictoolkit.net/>
- Blauert, Jens. *Spatial Hearing : The Psychophysics of Human Sound Localization*. Rev. ed., MIT Press, 1997.
- Borges, J. L. (1999). *Collected fictions* (A. Hurley, Trans.). Penguin Books.
- Borges, J. L., & Weinberger, Eliot. (1999). *Selected non-fictions*. Viking.
- Calvino, Italo. (1968). *Cosmicomics* (W. Weaver, Trans.; First edition.). Harcourt, Brace & World.
- Chowning, J. M. (1977). The Simulation of Moving Sound Sources. *Computer Music Journal*, 1(3), 48-52. <https://doi.org/10.2307/3679609>
- Danielewski, M. Z., Zampanò, & Truant, J. (2010). *Mark Z. Danielewski's House of Leaves* (2nd Edition). Pantheon Books.
- Hofstadter, D. R. (1979). *Gödel, Escher, Bach : an eternal golden braid*. Basic Books.
- Hofstadter, D. R. (1985). *Metamagical themas : questing for the essence of mind and pattern*. Basic Books.
- Lévy, Fabien. (2001). "Mutations: Composition Outwitted by Paradox." *Jean-Claude Risset Polychrome Portraits*. Ed. Castanet, Pierre-Albert. Paris: GRM - Institute National de l'Audiovisuel
- Moore, F. Richard. (1990). *Elements of Computer Music*. Prentice Hall.
- Pampin, J. (n.d.). *A Line* <https://dxarts.washington.edu/research/creative-work/line>
- Renouard-Larivière, Régis (n.d.). *DU POP À L'ÂNE* <https://maison-ona.com/catalog-0453ONA>
- Room impulse response data set*. Isophonics. (2008). <http://isophonics.net/content/room-impulse-response-data-set>
- Russolo, Luigi. (1986). *The art of noises*. Pendragon Press.

Sagan, C., Druyan, A., Soter, S., & Malone, A. (2000). *Cosmos : a personal voyage* (Collector's ed.). Cosmos Studios.

Shiffman, D. (2012). *The nature of code* (S. Fry, Ed.; Version 1.0.). D. Shiffman.

Stewart, Rebecca and Sandler, Mark. "Database of Omnidirectional and B-Format Impulse Responses", in Proc. of IEEE Int. Conf. on Acoustics, Speech, and Signal Processing (ICASSP 2010), Dallas, Texas, March 2010.

Udo Zölzer. (2011). *DAFX: Digital Audio Effects*, Second Edition (2nd ed.). Wiley.