Korean Electro-Acoustic Music Society's

2022 Annual Conference

PROCEEDINGS

October 15 Saturday - 16 Sunday, Lecture Room, Platform-L

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Contents

2022.10.15 Saturday		
10:10-10:30	Registration, Refreshments	
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10:40-11:40	Peter Ivan Edwards 피터 이반 에드워즈 National University of Singapore	[Keynote Speech] Situating Computing at the Center of Compositional Pedagogy: An Argument 컴퓨팅을 작곡 교육의 중심에 놓기: 논거
11:45-12:15	Caroline Owen 캐롤라인 오웬 Florida State University	*Badie Khaleghian's Electric Sky Blue* (2022): A Multidisciplinary Work for Piano, Dance, and Interactive Intermedia 베디 카레기안의 "일렉트릭 스카이 블루": 피아노, 무용, 상호작용매체를 위한 다원적 작품
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Situating Computing at the Center of Compositional Pedagogy: An Argument

Peter Edwards

The aim of this article is to build an argument in support of a belief I've come to hold after nearly 20 years of teaching composition, namely, that computer music skills are an essential component of modern compositional thinking, and hence, they should be a central component of composition pedagogy. Through a series of examples, I will show how statistical, procedural, and algorithmic thinking is a crucial part of modern compositional practice. Tracing the causes that brought about serialism, I will show how this pitch organization method transformed from a structural tool, as used by Schoenberg and Webern, to a statistical one as well as a component of more complex algorithms. I will then look at some examples of procedural and algorithmic works, specifically, from composers who are not associated with computer music. The final points of my argument will address ways that electronic music have seeped into compositional techniques for acoustic music. I will also explore some counterarguments and briefly address some potential challenges for the implementation of such a change in compositional pedagogy.

Let's turn to the twilight of tonality and the complementary rise of hyper-chromatic and atonal music that occurred at the beginning of the last century. I think of this as a moment when European art music lost its skeletal system because tonal harmony is more than a pitch organizational system: it infuses music with teleology and structure. This comes about through the departure from and return to a tonic, which reoccurs throughout a tonal work and defines phrases locally as well as form globally. Schoenberg seems to have been the composer who felt this loss most profoundly. Schoenberg's twelve-tone approach superseded his early atonal works, in part, because he could find no way to make atonal works that lasted more than a few minutes, aside from vocal works, which used the text to create form and narrative. (Schoenberg 1984) In the absence of tonality, a replacement for this large-scale structural scaffolding was necessary. In Schoenberg's case, it was not simply the twelve-tone system but, more importantly, his isomorphic permutation strategies used within that system that offered that replacement. (Haimo 1984) With these, pitch returned to a structurally relevant compositional component beyond the phrase level. But Schoenberg was a very traditional composer: the twelve-tone technique wasn't employed algorithmically. Instead, it offered harmonic coherence as well as flexibility for him to work motivically, like a 19th-century composer. Later composers didn't look to the row for this purpose; hence, the row took on new functions within the compositional process.

Webern was a much greater influence on post-WWII composers, I feel, due to the hermetic quality of his musical system. Put simply, everything fits together. In his serial works, the rows map onto each other through the common transformations of transposition, inversion, retrograde, and retrograde inversion. Aggregates break down nicely into 3 groups of tetrachords or 4 groups of trichords, and the form of a work articulates the design of the row.[1] (Stockhausen 1988) The hand found its glove, so to speak, a new skeletal system was born, and this was the future of music, as per the young composers at the Darmstadt Summer Courses in the late 1940s. With typical youthful verve, these young composers set off to serialize all musical elements. Boulez serialized rhythm and dynamic; Stockhausen attempted to serialize the overtone series and, hence, timbre. (Griffiths 2010)

While this story of serialism plays a substantial role in music history, it was short lived. Within a decade, the serialists were moving beyond serialism. I feel that the ramification of this fervent pursuit to transcend and rethink serialism rather than the serial works themselves has had a vastly greater influence on composition over the last 70 years. What resulted was a shift in compositional thinking that stayed with post-WWII composers and stays with us today, namely, an increased role for statistical, procedural, and algorithmic thinking in composition.

To demonstrate the early break from serialism, we can look at Nono's lectures from the early Darmstadt courses. In his lecture on the development of serial technique from 1956, he begins by looking at the earlier serial works by Schoenberg, demonstrating the use of all permutations, for instance, in *Variations for Orchestra*, as a method for thematic development. Through Schoenberg's subsequent implementation of hexachordal combinatoriality, multiple rows could sound at the same time yet complete an aggregate of all 12 tones. It was a first step toward consolidation. Webern's use of trichordal and tetrachordal permutation within the row was another step toward consolidating the permutations from the typical 48 to only 24. Finally, Nono argues that his use of the all-interval row makes retrogrades, inversions, and retrograde inversions unnecessary. (Nono 1975) In his lecture published under the title *The Development of Row Technique* from 1958, he states:

> "By developing the function of the twelve-tone row, which is no longer thematic, but only "row-like," the use of the four basic forms and their transpositions - which were important for thematic conceptualization - no longer seems necessary. It is sufficient to use two rows (typical for Webern) and finally a single row to derive from it the order of the intervals and further the whole compositional structure: the original row remains or is permuted." (Nono 1975)

The all-interval row is found in Nono's music by 1955 in works like *Il Canto Sospeso* and *Incontri*. He commonly composes with this row only partially, presenting segments, rather than complete cycles, of it. (Motz 1996) In an interview with Enzo Restagno, Nono discusses his use of the all-interval series in his 1955 work *Incontri*:

> "It was not about a series, but instead a catalog of intervals that were constantly mixed up in *Incontri* by means of a procedure that I already called positive and negative at that time. The positive was the duration and the negative the pause that corresponded to this duration. The result was a game with the shifting of sound values, whereby the beginning and end of the sounds threw any serial mechanicity out the window. It was really fun for me to try out how elements that could be systematic were completely jumbled up." (Nono/Restagno 2004)

The description above applies equally to movements of *Il Canto Sospeso*. These are already no longer serial works; the function of the row has changed in Nono's mind. It is no longer thought of as inherently structural or thematic, instead it guarantees something, namely, a statistical distribution of interval content, with each interval having, in Nono's case, an 8.33% probability of appearing.

Stockhausen articulates the importance of statistical thinking in his compositional approach in articles written around the same time as Nono's *Il Canto Sospeso*. In "From Webern to Debussy: Comments on Statistical Form" from 1954, Stockhausen outlines the development of his compositional methods that grew out of serialism. Starting with his point music (*punktuelle Musik*) in which "the largest formal unit was basically the individual note", he moved on to group composition (*Gruppenkomposition*) in which "group series correlate tones through higher-level, shared characteristics". But when composing with groups of sounds, Stockhausen argued, what often manifested was a phenomenon beyond the group's individual pitches and sounds. Through adjustments to the individual elements of the phenomenon, one can transform it. Stockhausen called this motion form (*Bewegungsform*) and realized that he could compose with it from a statistical perspective. The composer wrote:

> “Imagining statistical forms requires approximate definitions. It has to do with *degrees* of thickness or pitch groups; degrees of registers, of direction of motion, of speed, of speed change, average dynamics, dynamic change, timbre, and timbral mutation. When talking about statistical form, one uses character definitions like *average*, *primarily*, *considerably*, *generally*, *approximately*, and other similar descriptions.” (Stockhausen 1988)

In a computer-assisted composition environment, statistical strategies are common. Such strategies utilize randomness. Built-in functions for randomization through various distribution functions, random walks, weighted probability along with those for interpolation and perturbation are standard. With such functions, one creates lines, transformational trajectories, and musical characters that *generally* behave a certain way. While Stockhausen never used these tools for his music, his article demonstrates a need for them. Hence, one can see that already by 1954 a confluence between developments within composition and computing arises.

Yet, let us return to the story of serialism to see how it develops another branch of computer music, namely, algorithmic composition. Although Helmut Lachenmann isn't known as a serial composer, he certainly is influenced by serial thinking and has added his own develops. Like Nono, Lachenmann’s implementation of serialism is loose: so loose that we can’t really find it in his works. Nonetheless, his serial procedures are complex and rigorous. They serve as a means of inspiration, creating pre-compositional scenarios that he responds to artistically. Permutation isn’t achieved via the 4 common permutations. Instead, as Luis Pena demonstrates in his analysis of *Mouvement (vor der Erstarrung)*, Lachenmann uses a permutational row to reorder successive rows. This is even used to generate a row that then undergoes the same permutational process, relying on index manipulation for row permutation. He applies the results to duration and to pitch. He employs unorthodox, unique strategies to create what he calls a *Zeitnetz,* a scaffold-like structure that through successive revisions is partial wiped away. Again, these serial procedures are employed to give the composer something to start with and react against. Importantly, they are also arbitrary: there seems no aural relationship between the procedure and the piece. A different algorithm would have provided an equally *valid* scenario against which Lachenmann would have composed his work, that is, a different initial row would have yielded a different version of the composition, not a different piece. The rows and their processes are not meant to be heard; instead, they give the composer a starting point. Finally, it's worth noting that while completely algorithmic, Lachenmann didn't compute his *Zeitnetz*; everything was done by hand. However, Pena demonstrates in his thesis on *Mouvement* the computability of Lachenmann's process by coding the entire procedure in OpenMusic. (Pena 2004)

Lachenmann, however, is not unique in his use of algorithm to create structure. Let's look at some more transparent examples. Steve Reich's *Clapping Music* is a good place to beginning because it is very straightforward. This work uses a single rhythm that is 12 beats long. One player simply repeats this, while the other rotates the rhythm by one beat after 8 repetitions. This work is an example of Reich's phasing technique – this piece doesn't incorporate the phasing moments that you get in works like *Piano Phase*, but the concept and design are the same.

Philip Glass also has an early work called *1+1*. As is the case with *Clapping Music* for Reich, this piece is prototypical of Glass's other works from the same period. This is an indeterminate work involving 2 rhythms. The performer chooses the number of repetitions for each rhythm. Once each rhythm has been repeated the pre-determined number of times, the whole process is repeated but the number of repetitions may: 1) stay the same, 2) increase by 1, or 3) decrease by 1. The changes to one rhythm are independent of the other. A function that generates versions of this piece on the fly would be straightforward to code. The function would take the initial number of repetitions for each rhythm and a value for the number of times the process is repeated. Changes to the number of repetitions could be determined by a random walk with a lower boundary set to 1 – each rhythm must happen at least once – and an upper boundary, perhaps determined by the user of the function or set to an arbitrary value like 10. Glass's work could be simulated with other algorithms, provided they follow the rules of the piece. Random walk is, however, an obvious strategy.

John Cage appears in textbooks on the history of electronic music due to works like *Williams Mix*, *Imaginary Landscape No. 1*, and *HPSCHD*, created in collaboration with Lejaren Hiller, but in the field of algorithmic composition, he is not a substantial figure. Yet, few composers relied on algorithms for the creation of their work as much as Cage. Some of his algorithms are not easily codable. For instance, coloring imperfections on a sheet of music paper to determine notes is algorithmic but computationally complex to simulate in code. Yet, Cage is arguably most famous for tossing coins and rolling dice to determine parameters of his music. Cage was, therefore, a devoted user of Bernoulli trials, which are fundamental to probability theory and eminently codable. Furthermore, the composer Andrew Culver, working as Cage's assistant in the last decade of the composer's life, developed software that Cage used to create his *Europeras 1 & 2*, the *Music for* … series, and the time bracket pieces as well as his famous mesostics texts.[2]

First employed in 1976 in his work *Für Alina*, Arvo Pärt created a compositional system called tintinabuli, derived from the Latin word for bell. Using a two-voice texture, one voice uses only the notes of a triad, and the other voice utilizes the diatonic scale of the triad's root. This second voice generally moves stepwise. In his book on Arvo Pärt, Paul Hillier outlines consistent compositional strategies for note selection in Pärt's tintinabuli works. For instance, Pärt commonly writes passages so that the two voices alternate being the higher pitch. (Hillier 1997) An algorithm simulating Pärt's tintinabuli technique is very feasible.

Finally, the work of György Ligeti is also often procedural and algorithmic. These are well known, so I won't offer examples here. The micropolyphony and transformational processes found in his works starting around 1960 offer good examples and have been frequently written about. Articles by Ligeti, Clendinning, and Roig-Francolí are good starting points for more details on this. (Ligeti 1993, Clendinning 1993, Roig-Francolí 1995)

Each of the aforementioned composers is important in the history of contemporary music, representing a unique stylistic approach and utilizing algorithms that can be generated computationally. Note that I've intentionally avoided works by composers associated with algorithmic music, like Xenakis, to build my argument. Furthermore, with the works from Reich, Glass, and Ligeti, in particular, process serves to provide form to the works, that is, it is fundamental to the structure of the work and serves as the skeletal system for these musical organisms.

In addition to statistical and algorithmic thinking, the discoveries in the field of electronic music also play a crucial role in modern compositional approaches. By the 1950s, ideas from electronic music were already seeping into the world of acoustic music. Stockhausen's *Gruppen* from 1955 is a good example. The guiding metaphor for this work is the overtone series. Musical structures are imagined as magnified spectra. This is detailed in the composer's article *…wie die Zeit vergeht.* (Stockhausen 1988) Additive synthesis is at the heart of this work, which, in this regard, shares important traits with the composer's earlier electronic works, such as *Studie* I and II, which precede *Gruppen* by about 3 years. Related to this is spectralism, in which spectral analysis takes a central role in determining the harmonic nature of a composition. Two good examples are Tristan Murail's *Gondwana*, which determines its pitch constructions using spectral analysis of an FM synthesis routine that simulates a bell, and Gérard Grisey's *Partiels*, which uses the spectral analysis of an E pedal tone on trombone for its pitch material. (Fineberg 2000)

Additionally, a seismic shift in compositional material occurred in 1940s France with the introduction of Musique Concréte, which proposed that any recorded sound could be musical material. I think the profundity of this shift is not sufficiently acknowledged. Perhaps a simple question can expose the size of this shift: how do you motivically develop the sound of traffic? Of course, you can't because motivic development presumes that an analysis of the motive will yield composable elements, i.e., you will learn something about its interval content, pitch content, contour, note values, and ordering, and with that information, you can build a passage of music. A motive has an interior that is meaningful for traditional compositional technique; recorded sounds often lack this. Hence, an essential part of traditional technique is no longer useful for compositions that utilize recorded sound as material. So, how do you compose with such materials? This was as substantial a problem as the fall of tonality. Here composers don't just lose a formal means, they lose the means to move beyond the first sound of the piece. A similar question arises, by the way, with other 20th-century inventions like multi-percussion music and extended technique, both firmly part of compositional practice today. Solutions to this problem were various in the 20th century and included the Cageian approach of simply allowing any sound to exist next to any other – this had substantial ramifications on musical form in the 20th century – as well as a Schaefferian approach, in which timbre and envelope are considered. This latter approach even found its way into acoustic composition via Lachenmann's sound types of new music. (Lachenmann 1996).

In fact, Lachenmann's sound types - first articulated in 1969 as a provisional theory for thinking about the relationship between form, time, and sound - provide a link between Schaeffer and Stockhausen. While the sound types themselves resonate with Schaeffer's categorizations of sounds, Lachenmann argues that, when composing with sound types, the sum should be more than the whole, that is, individual sound types should be combined into what he calls a structure sound (*Strukturklang*), and the excerpt given in the article to demonstrate structure sound is from Stockhausen's *Gruppen*, a work rich in statistical forms. (Lachenmann 1996)

So, to review, training modern composers means teaching them how to compose with process, how to compose statistically using randomness, how to compose with algorithms, how to work with electronic sound, how to carry out spectral analysis of a sound, how to develop musical ideas with material that, as I put it, has no interior, that is, can't be broken down for exploration and extension like a motive. If this is the case, then the computer seems an essential tool for modern compositional practice because it can serve as an assistant for all of those tasks. Perhaps it's sensible to look at the situation this way: the computer is to modern composition what the piano is to traditional composition.

Let's take a moment to look at some counterarguments to what I'm proposing. One might state that the examples I've given are all from composers who didn't use computers to create their works. Clearly, the computer isn't necessary for composing such music. In response, I would argue that the examples offered were written before personal computers were commonplace. It is worthwhile speculating about whether the composers would have used computers and CAC software, if they had been available. What if they had learned coding while studying composition? It is arguably that in some cases they would have utilized these tools.

Another counterargument: outside of using music notation software, most current composition faculty members don't use computers to compose. So, clearly, one can compose procedurally and algorithmically without a computer. The response to the first counterargument is a good place to start a reply to this one. Additionally, different composers have different preferred working methods; some take great pleasure in composing by hand. The familiarity of the working method can trump any advantages of speed and accuracy offered by coding. Finally, there are many composers today who are (what I'd describe as) modern traditional composers who use modern harmonic practices, but nonetheless still write melodic-harmonic music. Some composers have greater interest in political aspects of music, in post-modern reference, and popular styles. For these composers, computer-aided composition or electronic music might hold little interest. But neither the technical limitations of the past, which shaped the education of current composition faculty, nor the aesthetic direction of major study instructors should be inhibitors to curricular reform designed to train the next generation of composers. We should enter into and build off of our students' world – one that has always been highly technical, where the internet has always existed, and in which computational thinking increasingly plays a role in their pre-university education. We should allow this world to influence not only how we compose but also how we teach.

One last counterargument: algorithmizing music where it is possible to do so is not just an issue of practicality and efficiency, it is an aesthetic issue. For instance, generating Glass's *1+1* using code may produce a valid realization of the work, but it's not the same as improvising the work. While I agree wholeheartedly with this argument, I think it is up to the composer to situate computing into their compositional method. I believe that many composers don't use the computer for composition largely because they don't know how to. They never arrive at the point where they need to decide how extensive the role of computing will play in their compositional process. The next generation of composers should be given the chance to decide this for themselves.

A final argument for my position: computing environments provide experimental spaces for composition. A composer can test algorithms. For example, one could evaluate the code for a passage of music in which there is a 9:1 ratio in the probability of high notes and low notes. If, after evaluating her program, the composer decides there are too many low notes, then she can experiment with a different ratio. Every variable in a function becomes a place to tweak outcomes until the musical result is what the composer desires. For composers who work computationally, this has enormous value when realizing their ideas. Environments like Max, OpenMusic, OpusModus, and others should be seen as creative, interactive spaces for exploration in sound and composition, and not solely as computer music environments.

If computing moves toward the center of compositional pedagogy, then a few changes will be needed in a composition curriculum. First, the dividing line between a degree in composition and one in computer music will need to be redrawn. To study composition will inherently mean, in part, studying computer music. So, how will these fields distinguish themselves? Second, 1-2 mandatory introductory courses on electro-acoustic music will not suffice for adequate training in the necessary tools for computer music. A richer set of courses will be needed, yet this will likely mean that other subjects will need to be removed from the mandatory course list. The loss of mandatory courses in a major always stir up heated debates. What should go? What is less worthy than courses in computer music, a subject that many major study instructors won't feel is worthy of being mandatory in this first place? Finally, major study instructors will need support in supporting their students. When composing with Max, for instance, designing a patch is part of the compositional process. If instructors are unfamiliar with the environment, then they will have difficulty assisting students with both the technical and the artistic problems encountered. Perhaps a full-time assistant for Max and Lisp troubleshooting will be required, perhaps team-teaching is a solution.

I believe that such curricular changes outlined above would require a significant paradigm shift on the part of faculty and students. For its success, they would need to filter down into primary and secondary school education, their content becoming something that prospective students think they will learn when they study composition at the university level. Yet, I'm confident that this will happen because we cannot hide from history. On the one hand, the influence of composers mentioned in this presentation has been substantial, and on the other hand, technology has advanced to the point that today the tools to build off of their contributions are sitting in your pocket right now.

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[1] To demonstrate this point, read Stockhausen's analysis of Webern's Concerto for 9 Instruments, op. 24, in which he analyzes the first movement. This can be found in the cited text. One not only sees one way that Webern works with row segmentation but also how important this is to the author and, hence, how influential it was on his musical thinking.

[2] The software can be downloaded for free at the following website: https://www.anarchicharmony.org/People/Culver/CagePrograms.html

Badie Khaleghian's *Electric Sky Blue* (2022): A Multidisciplinary Work for Piano, Dance, and Interactive Intermedia

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The central focus of this article, which I have adapted from my doctoral treatise, is my collaboration with composer Badie Khaleghian on a new work, entitled *Electric Sky Blue*, for piano, dance, and interactive intermedia. Furthermore, this document serves as an account of the collaborative and compositional processes of producing a new multidisciplinary work that bridges the art forms of dance and piano. I also provide an analysis of the dialogue between these media and interactive visuals and audio throughout the piece and, further, the structural and expressive significance of this dialogue. Lastly, I discuss reasons for the importance of producing multidisciplinary, intermedia works for twenty-first-century audiences.

Keywords: intermedia, multidisciplinary, piano, dance, interactive, Khaleghian

While I am a classically trained pianist, I grew up dancing ballet and various other styles for several years. By engaging in both art forms, I discovered the mutual impact that dance and piano had on one another in my life. Playing piano developed skills in rhythm, timing, and musical phrasing that I could equally apply while moving on a dance floor; dancing intertwined physical movements with musical gestures and rhythms, allowing me to internalize the music I was hearing in a very external way. This relationship between music and dance continues to impact the way I perceive and perform music, often manifesting itself through the way I physically move while playing the piano. I have always been fascinated by multidisciplinary projects that combine dance and music and had dreamed of somehow merging the two art forms together in performance. My collaboration with composer Badie Khaleghian has transformed this dream into a reality.

Background

This collaboration began while Khaleghian and I were both earning graduate degrees at the University of Georgia. Khaleghian, an Iranian-American composer, has produced a wide range of works, including solo, chamber music, orchestral, and electro-acoustic compositions. His music, which has been performed in Iran, the United States, Austria, Italy, and Canada, is heavily influenced by his Middle Eastern background and his social justice activism. Khaleghian has also cultivated a passion for collaboration, not only with other musicians, but also with artists and scientists, thus fostering an intersection of disciplines in his work. He particularly enjoys composing music for specific individuals and groups, and further, inviting them into the creative process.

After attending one of my performances in 2017 and learning about my dance background, Khaleghian approached me about collaborating, and we brainstormed a way to intersect piano and dance within a solo piece. The result was *Life Suite*, which we premiered in 2019. A multidisciplinary work for solo piano, dance, and fixed media, the piece combines both live and recorded solo piano and dance, all of which I performed. A deeply personal work, it features film footage from one of my old dance recital performances and explores not only my own identity as both pianist and dancer, but also the general concept of finding one's identity. A year later amid the COVID-19 pandemic, Khaleghian and I began discussing plans for a new multidisciplinary piece that would stretch beyond the scope of *Life Suite* in both its layering of various media and its incorporation of technology. The resulting composition, which I will further discuss in detail, is *Electric Sky Blue* (2022) for piano, dance, and interactive intermedia.

Terminology

While the terms *multimedia* and *intermedia* have been used interchangeably, there are nuances that differentiate them from one another. *Multimedia* quite literally refers the combination of "multi-", or "many," and "media," or methods of communication. These media can include audio, written text, video, and images, among other communication methods. *Intermedia*, on the other hand, includes "inter," meaning "among" or "between." Intermedia extends beyond merely the use of multiple media, more specifically referring to a fusing of media to form a culminating artistic product. Intermedia art has also been defined by its employment of new technologies.

Whereas *Life Suite* is considered a multimedia work, Khaleghian wanted this new project to be interactive, thus designating it as an intermedia work. In this case, the term *interactive* refers to the digital reaction of one medium from another in real time (e.g., visuals reacting to certain amplitudes played by an instrument or sounds reacting to physical motion). Khaleghian chose to compose a work in which several media—live piano, dance movements, visuals, and both fixed and live processed audio—are constantly in dialogue with one another. Lastly, he envisioned the work to be immersive for the audience, with multi-dimensional visual projections and multi-channel audio coming from sound speakers in multiple locations around the space. The process of bringing these technological and multidisciplinary ideas to fruition, which took over a year, required a multistep process that is outlined below.

Collaboration Process

Research

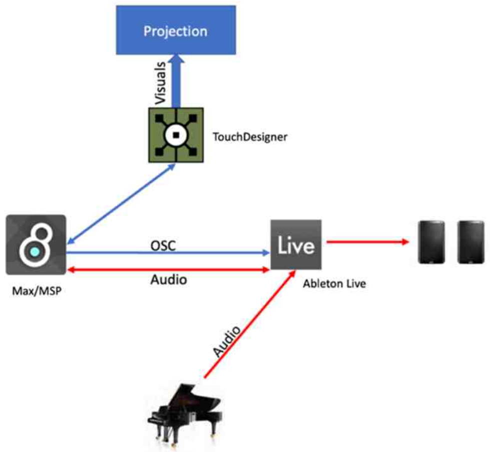

Figure 1. Diagram of software used in *Electric Sky Blue*, courtesy of Badie Khaleghian.

After our initial discussion in establishing a desire to create a multidisciplinary, intermedia work, Khaleghian conducted extensive research in the software and technology needed to bring piano, dance movement, visuals, and electronic audio into active dialogue with one another. Based on this research, he now uses a program called *TouchDesigner* to design all visuals, which are live processed throughout the piece. In order to capture my physical movements in real time, he uses *Microsoft Kinect*, a motion sensing input device that collects data from x, y, and z axes of eighteen different skeletal joints of my body. This data is then sent, via Open Sound Control (OSC) communication between applications on different computers, to a software called *Max/MSP*, a visual programming language specifically for music and multimedia. All the processed sound from Max/MSP is directed to *Ableton Live*, a digital audio workstation (DAW) used in composition and performance, via *Max for Live*, which, according to Ableton's website, allows users to construct their own instruments and effects along with tools for live performance and visuals. A diagram showing Khaleghian's use of these programs can be seen in Fig. 1.

Development

Following this phase, Khaleghian developed a body instrument using the Microsoft Kinect device. By moving my hands and feet along the axes mentioned above, I could manipulate the elements of pitch material, timbre, dynamics, pulse, and texture to create electronic music. In other words, Khaleghian developed a way for music and my movements to be as intimately connected as possible, with technology sensitively reacting to something so innately human. We then held workshops, in which we tested out different versions of Khaleghian's instrument with varied musical elements. We simultaneously engaged in continual conversations, brainstorming conceptual ideas along with what we wanted our project to convey to audiences. Inspired by a poem I had written about the color electric sky blue, one for which I have always had a particular affinity, Khaleghian decided to use this text as the basis for the work's structure:

Born in Autumn, in the crisp air of mid-October,
It takes you to places far away, with cypress trees and gravel paths along hillsides,
With medieval towns across the valley.
Places that have stood still for centuries,
With grasses blowing in the quiet all around.
It sits with the morning, still in its freshness and
Full of possibility for what a day could hold.
It longs for life, for adventure, for full breaths deep inside your lungs.
For running and jumping into a pile of crunchy leaves, with a child-like delight.
It hides the gray, the stormy, the deep rumbling that is still there.
It is not like the dark midnight, with all its shadows and anxiousness.
It nods along to a song of exuberant joy,
With an intoxicating beat you can't help but dance to.
Constantly shifting and morphing, round, plump, malleable.
It moves with leaps—bold yet graceful.
It befriends the rustling leaves in the trees, with the branches that frame it and
Bring out its electricity, its truest form, its most vibrant hue. (Owen 2021: unpublished)

Set in ten scenes, each of which is based on a line of poetry, the piece abstractly follows the poem's surface narrative while simultaneously outlining a broader journey—one that evolves from themes of birth and innocence to anxiety and struggle, finally leading to a sense of newfound resilience and authenticity. This narrative structure aided Khaleghian and me in constructing ideas about the dialogue between music and other media throughout the work.

Khaleghian then began to write music for certain scenes, which I would learn one by one. I also prepared to step into the additional role of dancer by retraining, brainstorming the types of movement I wanted to communicate depending on the scene, and consulting a choreographer for additional ideas. After holding multiple workshops over the course of several months, Khaleghian and I saw *Electric Sky Blue* through to its completion and first performance in March 2022.

To prepare the work for performances in a variety of potential venues and settings, Khaleghian created multiple versions of *Electric Sky Blue*. While it lasts approximately forty minutes in its entirety, a shorter version of the work could be performed from Scenes 7 through 10. He also designed the configuration for performance setup to be flexible, depending on the capabilities of the venue. The most ideal conditions consist of a dark space with immersive projection and sound, but the audio can be sounded through as few as two channels, if necessary. Realizing the logistical constraints of his initial conception of implementing panoramic visuals to surround the performer and audience, Khaleghian also adapted this idea, creating a two-dimensional plane to project visuals on both the floor and back using screens. If this option cannot be a possibility in a venue, however, visual projections on just one back screen are still effective. A complete technological diagram for *Electric Sky Blue* is shown in Fig. 2.

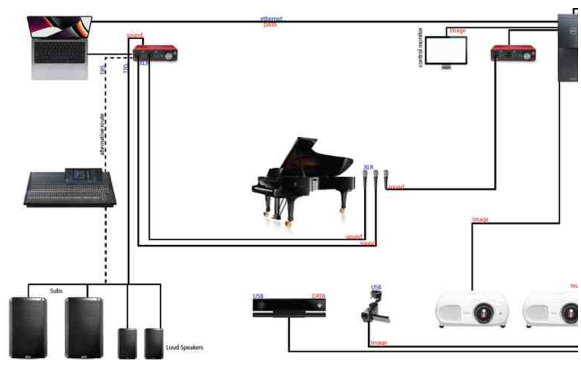

Figure 2. Complete technological diagram for *Electric Sky Blue*, courtesy of Badie Khaleghian.

Result: *Electric Sky Blue* (2022)

Formed out of this multidisciplinary, intermedia approach to composition, *Electric Sky Blue* showcases the extension of possibilities used to shape the structure of a piece of music; Khaleghian not only accessed standard musical elements such as pitch, harmony, rhythm, etc. but also to multiple artistic media and technologies. The formal structure of *Electric Sky Blue* is primarily shaped by the addition and resulting combinations of media; this dialogue between them shapes the piece's narrative, as well. This approach to form and narrative is captured below in the following brief survey of scenes.

Prelude

As Khaleghian and I wanted the piano to serve as the cornerstone of the work, we chose to begin and end the piece with solo piano alone. *Electric Sky Blue* opens with an unsuspecting Prelude, as though the listeners are about to experience a more traditional solo piano recital. The scenes which follow, however, progressively step beyond these expectations. The Prelude follows an ABAB formal structure and stays within a tonal/modal harmonic language; the A material, for example, has a tonal center of D and hints at Phrygian and Dorian modes with the presence of E-flat and B-natural, respectively (Fig. 3). The Prelude also introduces pitch collections that are recalled later in the piece, such as the strong presence of 01 dyads. As shown in his score indications for continuous pedal, also seen in Fig. 3, Khaleghian develops the idea of building resonance of sound throughout the Prelude. Serving as a musical motif, this resonance foreshadows the presence of ambient electronic sounds in the scenes to follow. The repetitive nature of its motivic gestures also foreshadows the delay effects present in the final Scene 10, as discussed below on p. 7. As I play, a simple shade of sky blue is projected, marking the visual nature of the piece, as well. This blue backdrop gradually progresses to a more obvious sky with moving clouds. This shift not only introduces visual animation but also contributes to the sense of beauty and purity at this point in the work's narrative.

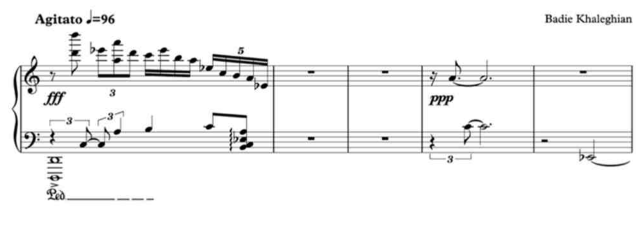

Figure 3. Tonal/modal harmonies and continuous pedal notation at the opening of the prelude, mm. 1-5.Scene 1

The end of the Prelude converges with Scene 1 when, at the moment the final chord is struck, I introduce spoken text from the first couple of lines of poetry: “Born in Autumn, in the crisp air of mid-October, / It takes you to places far away…” As I speak into the amplified piano, I simultaneously play a singular melodic line reminiscent of the rhythm and inflection of each phrase. The melody acts in counterpoint with the poetry, first as a more complete response to each phrase, but then entering sooner to overlap with the spoken text in a delay effect (Fig. 4). This introduction of the human voice is a first step in thwarting listeners’ expectations and thus introduces a multidisciplinary element of surprise.

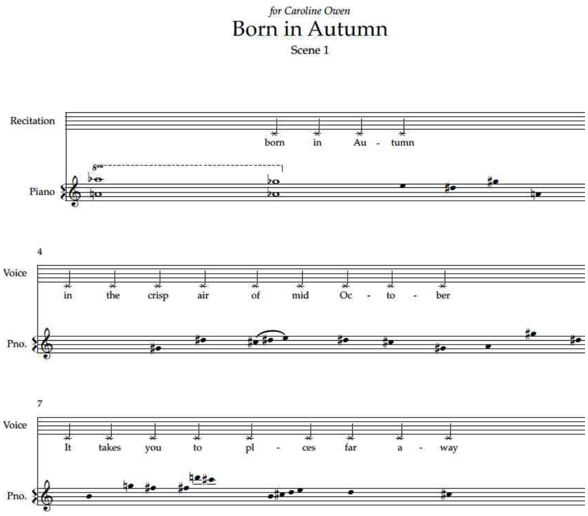

Figure 4. Counterpoint between spoken text and piano melody in Scene 1.

Scene 2

Figure 5. Opening of Scene 2, with suspended chords and soft dynamics, mm. 1-10.

Based on the lines, “It takes you to places far away, with cypress trees and gravel paths along hillsides, / With medieval towns across the valley. / Places that have stood still for centuries, / With grasses blowing in the quiet all around,” Scene 2 features suspended chords void of any functional harmonic resolutions, along with soft dynamics that transport the listener musically (Fig. 5). Khaleghian primarily uses stacked tertian and quartal harmonies, along with sevenths and minor seconds, to construct these chords. While not functional, the harmonic language is still quite modal; the opening lines, as shown in Fig. 5, are largely comprised of pitches in the C# Dorian scale, for example. The end of Scene 2 features tone clusters interspersed with the opening chords, perhaps signalling an eventually departure from tonality later on in the work. The visuals in this scene transition from a blue sky to darker shades of blue, and the visuals subtly move and morph as they react to amplitudes produced at the piano. This scene therefore introduces the interactive nature of *Electric Sky Blue* for the first time, adding a new surprise.

Scene 3

Scene 3 begins similarly, with flowing visuals swirling in fire-like patterns reminiscent of the sun projected while I play chords broken up in shimmering textures (Fig. 6a) in the upper registers of the piano. These elements evoke the following line in the poem, “It sits with the morning, still in its freshness and / Full of possibility for what a day could hold.” Khaleghian indicates that, within these chordal trills, certain pitches should pop out of the texture to form a melodic line between chords. Similar to Scene 2 in its harmonic language, Scene 3 features chords constructed from quartal and, in this case, quintal harmonies, in addition to some chromatic motion between chords (Fig. 6b). The textures and slow-changing harmonies allow me to lift my hand in the air between chords during the repeat of the materials, as indicated in the score (Fig. 6b); this vertical hand motion not only cues electronic sounds based on the played harmonies but also cues motion-affected visuals that change color depending on the height of my hand. At this point, instead of reacting to the piano’s sound, the visuals are reacting to my motion, thus introducing the concept of interactive motion-capture technology in the piece.

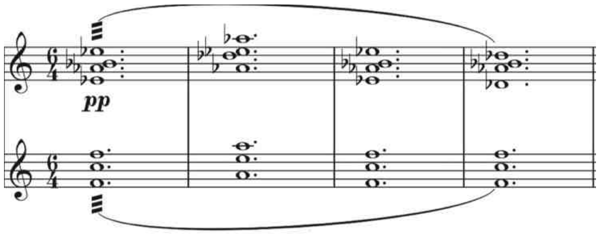

Figure 6a. Opening of Scene 3, with indication of shimmering chordal trills, mm. 1-4.

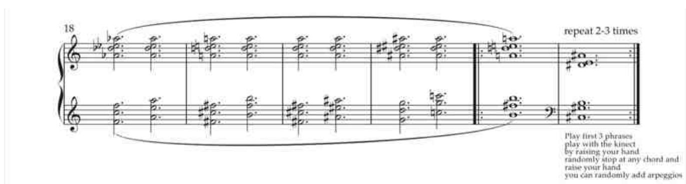

Figure 6b. Chords built from quartal and quintal harmonies, some chromatic motion between chords, and indication to lift hand to activate Microsoft Kinect, mm. 18-22.

Scene 4

Scene 4 marks yet a further important point in the piece's structure as I transition away from the piano bench and move around the space for the first time. After establishing the new interaction between movement, sound, and visuals, I more directly explore Khaleghian's Kinect instrument, in which my motion cues various electronic pitches and arpeggio gestures; these pitch frequencies form a pitch collection (G2, D3, F#3, A4, C#4, C4, D#4, E4, F4, G#4, B♭5, B5, C#5, D5), which Khaleghian also utilizes in the upcoming Scene 5. By featuring a twelve-tone collection, the piece has shifted from tonality into a fully chromatic language at this point. Each of the pitches and arpeggio gestures is assigned to a box on a 4 x 5 grid, designed by Khaleghian in Max/MSP. He replicates this grid with the Kinect device, which gathers live data from my movements across x and y axes on the ground and thus cues certain electronic pitches to be sounded. As this scene corresponds with the poem's lines, "It longs for life, for adventure, for full breaths deep inside your lungs. / For running and jumping into a pile of crunchy leaves, with a child-like delight," I become a character awestruck by the magical nature of this interplay of media and move with child-like hops and leaps around the space, exploring the Kinect instrument. The visuals, made up of bright and colorful shapes, also trace my movements.

Scene 5

As in the poem with the line, "It hides the gray, the stormy, the deep rumbling that is still there," Scene 5 marks a shift from light to dark, from carefree to rigid. I am pulled back to the piano bench, which I show in my movements, and begin to play virtuosic passages consisting of nearly constant strings of sixteenth notes (as seen in Fig. 7), juxtaposed with sections containing more rests. To match this shift in the narrative, Khaleghian used a much more intellectual approach in his composition of this scene's piano part, writing algorithms to generate both musical and visual materials. As in Scene 4, he used a similar idea of a grid, this time creating a conceptual 20 x 20 grid. Each of the 400 modules on this grid cues a musical event in an algorithm—either a certain pitch, a rest, or a transposition.

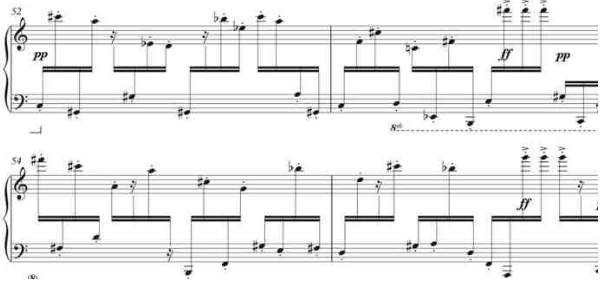

Figure 7. Textures of rapid, widely-spaced sixteenth notes interspersed with rests in Scene 5, mm. 52-55.

As mentioned above, Khaleghian drew from the same pitch collection of fourteen pitch frequencies from Scene 4, this time spacing the pitches out across the different registers of the piano. In the lower registers, he created wider gaps between pitches, utilizing intervals such as major and minor sevenths, minor ninths, and tritones; he narrowed these gaps in the higher registers, frequently using intervals such as minor seconds. These pitches and their repetitions formed a large number of the modules in the grid used for the algorithm; the remaining modules indicated a rest or one of fourteen different kinds of transpositions, also repeated. The order in which these modules were cued was determined by Khaleghian's algorithm.

Khaleghian also created an algorithm for the visuals in this scene using an amplitude follower. After he took these fourteen pitches and played each of them on a keyboard for one second, the amplitude follower translated the sounds to cue various visual lines to be projected. After fourteen seconds, the pixel modules used for these visual lines cued the music algorithm to generate new pitch materials, rests, and transpositions, which would then be translated again to visuals, in an infinite loop of events. Using the control of a metronome, Khaleghian ran this interaction of algorithms for five minutes, while simultaneously using a slider control mechanism to control range, to create the musical materials for Scene 5.

Figure 8. A moment of intervallic and rhythmic consistency before erupting into a glissando, mm. 67-73.

By using a musical algorithm to generate pitch and rhythm materials more randomly, Khaleghian moves away from any kind of identifiable pitch collection or clear overarching formal structure at this point in the narrative of *Electric Sky Blue.* He did have to significantly modify the generated materials, however, in order to make the piano part mostly playable. He added rests in various places to account for large jumps, and he created intervallic and rhythmic consistency in certain sections to provide a sense of momentary stability (Fig. 8). The visual zigzagged lines projected as I am playing the piano serve as visual proof of how Khaleghian composed this scene, although in real time they are just reacting to the piano's amplitudes (Fig. 9).

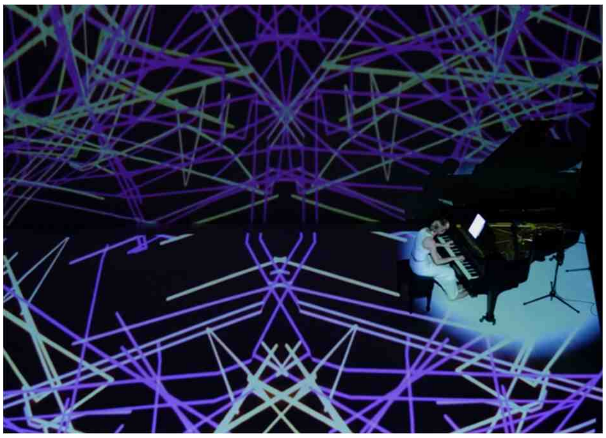

Figure 9. Visuals of rigid lines and shapes reacting in real time to the amplitudes from the piano. Photo taken from performance at Rice University in April 2022.

Scene 6

Not only does Scene 6 reach the darkest point in the narrative with the line, "It is not like the dark midnight, with all its shadows and anxiousness," but it is also the climactic point technologically, as I once again leave the piano bench to explore with the Kinect instrument. In this scenario, my body movements along x, y, and z axes control various pitch materials, dynamics, and textures, along with visual shapes, sizes, and colors; this relationship between different body movements and specific musical and visual elements is shown in Table 1. While exploring the instrument to manipulate the sounds and visuals, I use more disjunct, rigid movements to match this point in the narrative. I finally return to the piano and play identical material heard earlier from the opening of Scene 3; this time, the piano sound is manipulated electronically using granular effects and detuner patches, which give the original material a darker, out-of-tune quality.

Right and Left Hands, X Axis	Cues 9 pitches
Left Foot, Y Axis	Cues sound effects
Right and Left Hand, Y Axis	Controls audio dynamic and visual texture intensity
Body Z axis	Controls visual shapes and size

Table 1. Musical and visual cues from body movements in Scene 6.

Scenes 7-8

Narratively, Scene 7 marks the beginning of a shift away from darkness. Evoking the line, "It nods along to a song of exuberant joy, / With an intoxicating beat you can't help but dance to," live piano engages in conversation with fixed electronics, emitting an effect that the two media are affecting one another in real time. The nearly constant metric changes create rhythmic intrigue throughout the scene, contributing to the idea of "an intoxicating beat," and the repeated low bass Es (Fig. 10) suggest a return to modal/tonal harmonies, which were absent in Scenes 5 and 6. The visual projections, consisting of two layers, shift and change color via an amplitude follower, which captures the piano and electronic amplitudes. The first layer contains blurred out circles, which pop out of the background in sync with the sound of both piano and electronics. The second visual layer features a dancing silhouette, taken from film footage of myself dancing, and appears only when I play piano. In terms of colors, however, Khaleghian programmed them to change depending on which range of the piano I played in any given moment; they were not impacted by electronic sound.

Figure 10. Repeated low bass Es and metric changes in Scene 7.

Musically, Scene 8 serves as an afterthought to Scene 7, capturing nearly all the musical materials present before. Instead of engaging the piano again, I dance most extensively at this point in the piece. I collaborated with choreographer Anna Owen to create movements inspired by the line "It is constantly shifting and morphing, round, plump, malleable." The resulting choreography features movements that fluidly transition into one another and maintain clarity in shape. Many of the movements are circular, as in the turns I make in a large circle around the stage or in the poses I hold with my arms. Some movements are slow, creating a moment of suspension, while others are sharp and quick, following the occasional moments of rhythmic drive in the electronics. The projected visuals, reacting to the electronic sounds, are also fluid and constantly morphing to match the line in the poem. Unlike those of Scene 7, the color changes in Scene 8 are all randomly generated, although Khaleghian still chose specific colors to be used.

Scene 9

Set to the line "It moves with leaps—bold yet graceful," Scene 9 marks the arrival of relief in the narrative and is a culminating point as an electronically manipulated recording of my own recitation of the poem is heard through speakers. This is the first time that spoken text is heard once again since Scene 1, thus reinfusing a more human quality into the piece. As listeners hear the lines of the poem, I walk around the room and use the Kinect instrument one last time, to clear with my hand a blacked-out painting, made by Khaleghian's grandfather, Shoja'addin Khaleghian, of autumn leaves and a blue sky (Fig. 11). Narratively, this action of clearing away darkness to reveal shades of blue and orange represents the moment of once again finding hope and clarity after journeying through instability and confusion. Rather than using a simple sky blue background, we chose this painting as it not only ties back to earlier lines of the poem but also captures the idea that the blue sky is now even more vibrant when framed by the leaves than on its own. This image foreshadows the final line in the poem, which inspires the upcoming final scene.

Figure 11. Painting by Shoja'addin Khaleghian, the upper portion of which was used as a visual backdrop in Scene 9.

Scene 10

Figure 12. Opening of Scene 10, with limited pitch materials in upper piano registers.

Set to the poem's final line, "It befriends the rustling leaves in the trees, with the branches that frame it and / Bring out its electricity, its truest form, its most vibrant hue," Scene 10 represents a calming down of technology and media, refocusing the end of the piece back to the piano. The music for this scene is very intimate and quiet, with limited pitch materials in the upper registers of the piano (Fig. 12). The tonal center is C#, thus confirming a return to a tonal harmonic language and recalling the opening of Scene 2 with its harmonies surrounding the C# Dorian scale. The presence of B# in this scene, however, suggests a C# harmonic minor scale.

Khaleghian still employed technology in the projected visuals. Initially, he used a motion capturing device to display not only my silhouette at the piano, but also two copies of my silhouette behind it, each following a line of delay to create a delay effect of the silhouette. Each delayed copy of the silhouette corresponded with an electronically manipulated, one- or two-second audio delay of the piano sound, fusing a synthesis of visual and aural delay at certain points in the scene. Musically, this delay ties back to the Prelude's echo effects of repeated gestures, like the three final iterations of diminished octaves and minor sevenths at the end of the Prelude (Fig. 13). The projected silhouettes were set against a black and white background sketch of the surrounding space; this visual data was collected by the Kinect device as I walked around the space in Scene 9, thus further connecting the two scenes.

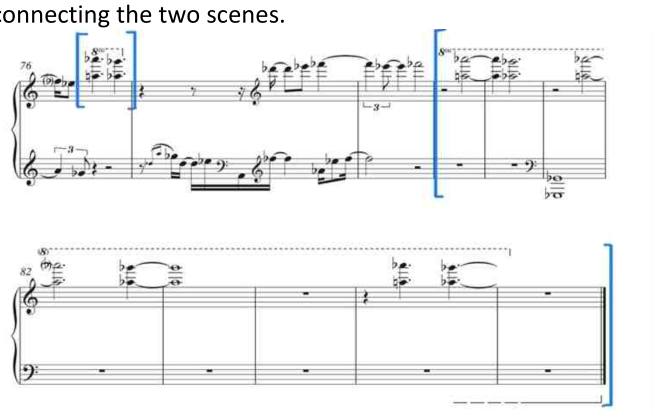

Figure 13. Motive of vertical diminished octave and minor seventh, repeated three times at the end of the Prelude, mm. 76-86.

After we premiered the work, however, Khaleghian and I decided to alter the original visuals to tie into the work's narrative arc more clearly. Khaleghian changed the black and white background to the same sky blue that was present at the beginning of the piece. He did still choose to use the Kinect to collect visual data from my walking path in Scene 9; these motions are now captured in black sketches and lines over the blue, as shown in Fig. 14.

Kahleghian also retained the initial audio delays of the piano sounds. This concept of delay in Scene 10 refers less directly to the poem's final line than to a broader reflection on personal transformation. Khaleghian views Scene 10 similarly to a coda, a retrospective commentary on dualities—of my own role as both pianist and dancer, and of the opposing emotions one can simultaneously hold after undergoing struggle and growth. Khaleghian drew on this feeling of bittersweetness as he chose to end *Electric Sky Blue* in melancholic beauty and simplicity rather than triumphant positivity. This sense of quiet at the end completes the narrative arc of the piece, settling back to the calmness present in Scenes 1-3 before the intensity of Scenes 5-8.

Figure 14. Updated visuals of Scene 10, with the outlines of my Scene 9 walking path projected over a sky blue background.

Motives for a Multidisciplinary Intermedia Approach

After conveying an account of our collaboration process and discussing the resulting *Electric Sky Blue* itself, it is important to highlight reasons why Khaleghian and I chose to pursue this project with specifically a multidisciplinary, intermedia approach in mind. Firstly, we believe that this genre effectively displays connections among art forms and, therefore, holds an artistically meaningful purpose. Utilizing multiple artistic disciplines in combination with technology provides both composer and performer with more tools to create a multi-layered work. This approach engages multiple human senses, allowing both the performer and audience members to experience the artistic work in a multi-dimensional way. Rather than remain in separate spheres, the media can interact with one another to contribute to a complete work of art.

Secondly, this project was a unique opportunity for both Khaleghian and me. By capitalizing on my dance background and his passion for multidisciplinary work, we saw the project as an innovative creative outlet for both performer and composer. We further believe that this multidisciplinary, intermedia approach can be an exciting artistic path forward for other composers and performers who would like to be able to combine multiple skillsets in their artistic work. We also believe that, with both its multidisciplinary nature and extensive use of technology, this genre has the potential to connect with a twenty-first-century audience and break down barriers between classical music and other genres. This approach, for example, further challenges the notion that acoustic and electronic compositions should stay in separate realms. It also suggests the idea that a music performance does not have to be a solely aural experience, but also a visual one, in which the performer can move naturally without being accused of contriving expression.

Electric Sky Blue was produced with the intent of providing a unique musical experience to listeners—one that invites people to connect with live music, dance, and interactive visuals and audio simultaneously. Immersive art exhibits have continued to gain popularity around the world, and *Electric Sky Blue* integrates this concept with live music and dance. Khaleghian and I continue to discuss ways to make this project more accessible by shedding some of the barriers present in traditional classical music concerts. There is often an invisible wall separating performer from audience in these settings, thus creating an atmosphere of formality and rigidity. While *Electric Sky Blue* can be performed in traditional concert halls so long as they have the necessary technology, we plan to perform it in less traditional venues, such as art galleries and black box theaters. We have also implemented flexible seating options on the ground and stage in hopes of bringing the audience into the performer's space and drawing them into an intimate artistic experience.

For future performances of *Electric Sky Blue*, we are considering various ways to incorporate audience involvement in the performance process itself. For example, in settings that allow audience seating in the stage area, Khaleghian plans to develop a way to project visuals onto audience members that can react to their movements, as well. We also have plans to release a digital immersive version of the work on YouTube, hoping that *Electric Sky Blue* will appeal to audiences who are not traditional arts supporters. With its use of multiple art forms and technology, we hope that at least one of these media will appeal to nearly everyone.

I would like to thank Badie Khaleghian, my friend and collaborator, for seeing the potential in my background in dance that has led to our meaningful collaborations over the last four years. Thank you for dedicating so much time, research, and hard work to

produce our *Electric Sky Blue*. I am inspired by your brilliant mind and your unwavering drive to create new and impactful art. You have taught me how to think creatively, take risks, collaborate, and not give up. I hope we can continue our work together for many years to come.

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Translanguaging in Mexican Electronic Music Instrument Designers

Abstract

The technical language surrounding electronic music instruments is continually expanding with their increased popularity and use. The field's prioritization of English, the most commonly used language among manufacturers, presents a language barrier for non-native English speakers. New generations of independent electronic music instrument developers in countries like Mexico utilize a mix of English and Spanish to label and describe the features and functions of their products. This is due to a lack of terminology in Spanish coupled with a desire to compete in the global market. My paper highlights current examples in which Mexican builders like Paradox Effects engage with English and are actively searching for creative ways to enrich audio jargon in Spanish. Using objects or artifacts as hermeneutic, I delineate a methodology that considers perspectives from fields like critical linguistics and science and technology studies (STS) to highlight the role English plays in creativity and sonic imaginaries for the non-fluent.

Keywords: electronic music instruments, translanguaging, sonic imaginaries

> I FELT… That the book I shall write will be neither in English nor in Latin; and this for the one reason…namely, tha the language in which it may be given me not only to write, but also to think, will not be Latin, or English, or Italian, or Spanish, but a language in which dumb things speak to me, and in which, it may be, I shall at last have to respond in my to an Unknown Juddge.
>
> –Hugo Von Hofmannsthal*, The Letter of Lord to Chandos, 1902*

I first became interested in the way electronic music instruments (EMIs) are designed and marketed working at a small music store in the town of San Ysidro which is the southernmost city in California bordering Mexico. Our clientele consisted mainly of musicians and students from Mexico and the U.S., and our interactions were predominantly in Spanish. However, when it came down to discussing electronic music equipment, the use of English was unavoidable. Although it is fairly common to switch between English and Spanish in a border region like San Ysidro and Tijuana, one thing that remains consistent is when it comes to sound equipment and an EMI Spanish speakers must adapt to English due to a lack of terminology in labels, manuals, and marketing material in their native tongue. Recently a new generation of users and instrument manufacturers has emerged in Mexico who are engaging with English in ways that illustrate what linguistics scholars refer to as *translanguaging*. While early scholarship regarding the term is rooted in pedagogy, more recent work in critical and applied linguistics has shown how it can be adapted into a practical theory. My aim is to enlist these practical approaches to reading labels and marketing materials of two EMIs designed and manufactured in Mexico to illustrate the tensions between English and Spanish that happen at the *interface* level. Because language does not affect the functionality of an EMI, I bring into conversation scholarly work from the field of science and technology studies (STS)to parse out the role English plays in both mediation and commercialization, as well as its potential stifling effects on what James Mooney and Trevor Pinch refer to as *sonic imaginaries.*

Electronic Music Instruments

There exists a lack of consistency with regards to what is considered an EMI. The list may cover anything from a transistor-based guitar pedal to a complex sequencer that uses MIDI and a microprocessor. Controllers do not make a sound, but mediate between a user and music software. Recording devices record and reproduce sound, and are sometimes treated as instruments. From a legal standpoint, U.S. agencies like the FCC regulate equipment under Title 47 of the Code of Federal Regulations and categorize based on specific concerns regarding their components. The task of taxonomizing EMIs is beyond the scope of this paper, and for the purposes of this paper, I refer to any electronic device designed for the musician or performer. However, all of the aforementioned examples are important to consider as forces or practices that contribute to the way in which design evolves, but in other cases stays consistent.

Bert Bongers provides a useful birds-eye view of the evolution in technology surrounding musical instruments from *objects* (drums, cymbals) to *passive mechanical systems* (saxophones, violins) to *electric* (electric guitars) to the present-day instruments that "are combinations of (successive) technologies" (Butler, 2017, pg.2). EMIs offer new possibilities for music making and expression, improve workflow and accessibility, and by consequence increase the potential for new users to adopt them. A chronological trace of innovation provides scholars ways to study, unearth, or critically engage with the effects of technology on music-making and sound-recording technology, as is the case of tape music, musique concrete, or sampling. The breadth of academic inquiry has grown exponentially with regards to EMIs. Recent scholarly work surrounding emerging music technology is concerned with the impact they have had on performance and improvisation (Butler, 2014), the motivations and desired outcomes when designing new instruments (Emerson & Eggerman), or the influence on the piano keyboard on interface design (Dolan). The focus of this paper is to bring into light an aspect of design that has evolved into fixity: English is the lingua franca of design and marketing of EMIs and this brings up interesting questions surrounding language use among users whose native tongue is not English.

Interface and Labels

EMI labels, marketing materials, and manuals are meant to show what an instrument was intended to be used for. Many users spend time with images or copies of manuals before they are able to physically own an instrument. The words on the interface will usually point to a function, range, or signal flow of the instrument and describe its "affordances" (Gibson, 1977, as cited in Butler, 2017) The labels and instruction manuals are then an extension of what is often referred to as the "interface." In *Playing Something that Runs*, Mark J. Butler discusses the term interface as a *type* of EMI largely concerned with mediation between a performer and a technology, but extends the definition stating it "denotes something more than simply the mediating technology; in particular, it refers to the actual site of mediation: the surface of the mixing board and sliders, or the graphical representation on the screen of the computer" (2017). Butler's definition of interface is useful because it illustrates mediation in a way that includes the visual layout of an EMI not just in terms of functionality or at the "macroperception" level (Verbeek 2017). Butler is concerned with the physical design of the instruments and affordances they provide to performers and improvisers. This, however, implies a familiarity with the instrument after spending time working with it. By looking at the practices of two Mexican EMI companies, I problematize the idea of mediation and performance to include language as part of the schema.

Translanguaging Practice Theory

The term "translanguaging" has its origins in linguistics work concerned with bilingual education. Li Wei states it was "not originally intended as a theoretical concept, but a descriptive label for a specific language practice" (Wei, 2017). A definition of "translanguaging" that is helpful to frame this paper is as "the language practices of bilinguals not as two autonomous language systems as has been traditionally the case, but as one linguistic repertoire with features that have been societally constructed as belonging to two separate languages" (García and Wei 2). In *Translanguaging as a Practical Theory*, Li presents a way in which the term can be extended into a practical approach to language practices beyond the classroom. Another important feature of Li's approach is that it is meant "not to offer predictions or solutions but interpretations that can be used to observe, interpret, and understand other practices and phenomena" (11). I agree with this method because my intention with interpreting the language practices in my case studies is not to speculate on the future practices of Mexican designers or present the pervasiveness of English as a problem, but rather activate a new line of inquiry that pertains to agency and technological innovation.

Materiality of Language

The spread of English across the world has often been studied as a result of globalization, cultural hegemony, and a homogenization of culture. My aim is not to delve deep into the causes and effects of this phenomenon, but to enlist the word of critical linguistics to illustrate the localized ways in which English is employed by two EMIs designed by Mexican companies who design, build, and market their products in Mexico to the rest of the world. To clarify, my first case study, Paradox Effects and their guitar pedal Fuzz E Cat, is located in Tijuana, Mexico, within the border region; and my second case study is Bocuma Synths, located in Guadalajara, Mexico, 2,200km south of the border. Although it would be a monumental task to describe the different relationships both companies have to English from a geographical and cultural standpoint, it provides insight into the differences and similarities in their translanguaging practices.

Another important reason why I chose a translanguaging practice theory as a method is because it allows me to cast my peers and interlocutors within a more robust framework of agency. As Latour explains, “We follow the actors’ own ways and begin our travels by the traces left behind by their activity of forming and dismantling groups (Latour 29). I argue that having a single language to learn, discuss, create, and ontologize sonic phenomena stifles creativity. In *Decolonising the Mind*, Ngũgĩ Wa Thiong'o argues that “language, any language, has a dual character: it is a means of communication and a carrier of culture” (Thiong’o 13). This does not mean, however, that companies are unable to reappropriate the English language to make new instruments representative of their vision. By bringing translanguaging into the study of EMIs I illustrate how interfaces might be designed and conceived in a way that extends mediation to include language. It is worth mentioning that I employ my own position-as-method as a member of the community that I am researching. Therefore my interpretation is both from within the locality and from a theorized perspective.

Case Study 1: Paradox Effects

To compete in global markets, many products are labeled in English, not just musical instruments. This ebb and flow of global vs. local practices requires more complexity in our thinking of language practices. Linguistic scholar Alaistair Pennycook, an important figure in the study of global Englishes, states that

> The multidimensional nature of both dominating modes of globalization - corporatization, capitalization, conceptualization - and of resistant and localizing modes - transculturation, translocalization, transformation - lead to very different linguistic and cultural practices than international domination or national localization. It is a far more dynamic space of flows.

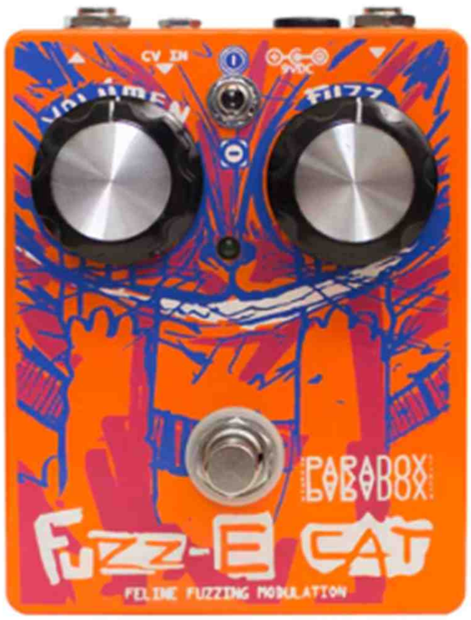
According to Pennycook, an effective theorization of linguistic practices along the axes of global vs. local must encompass a definition that allows for more than one form of globalization. One such case is the manner in which Mexico has become a site of outsourcing manufacturing processes for transnational companies.

Efrén Castro, one of the co-founders of Paradox Effects, studied Electronic Engineering at Universidad Autónoma de Baja California. His growing interests in effect pedals began to clash with the school’s focus on the job market. The effects of globalization extend to universities' curricula due to the growing demand for engineers in maquiladoras. In theory, a career in electronic engineering offers a range of possibilities for the graduate, but in practice most roads lead to working for a transnational company in one of their factories. During his time at UABC, Castro, who is also a musician, learned about electronic circuits. He began to tinker with a circuit that is commonly adopted in DIY circles, the fuzz pedal.

In a box sitting in my studio I keep guitar pedals that I obtained when my main instrument was the electric guitar and bass. It doesn’t get much use lately because I shifted my musical practice to synthesizers, but I keep it as part of my collection because it is one the first effect pedals designed, manufactured, and marketed in Tijuana, Mexico by Paradox Effects. The Fuzz-e Cat, as it is called, is “a roaring oscillatory feline, a highly sensitive Fuzz that creates many textures with few controls” (Paradox Effects, 2017, para. 1). Although the marketing materials are all in English, the faceplate looks like an electrified cartoon cat with two knobs for eyes which is labeled in Spanish and English. As shown in Figure 1, the left knob is labeled “Volúmen” and the right one “Fuzz” (figure 1).

Figure 1

Fuzz-E Cat effect pedal



Note. Fuzz-E Cat front panel. From https://paradoxeffects.com/products/fuzz-e-cat [digital image]

In the same manner that the pedal’s zoomorphic design layout only contributes to the aesthetic quality of the pedal, I argue that the use of the word “Volúmen” is a symbolic gesture signaling the nationality and identity of the company. However, at the time of release, Paradox marketed their pedals in English. Having a somewhat strong social media presence, the company posts videos on YouTube, Instagram, and Tik-Tok in Spanish, some of them with English subtitles.

Paradox markets the Fuzz-e Cat as “a silicon based effect, our amorphous take on the Fuzz Face topology” (Paradox Effects, 2017, para. 1). The Fuzz Face mentioned in their blurb is a highly regarded effect pedal designed in 1966 by Arbiter Electronics Ltd. and made famous by artists like Jimmy Hendrix. Its circuitry has been reimagined by many effect pedal designers from across the globe due to the ease with which it can be built and modified. But by engaging with the Fuzz Face circuit in their product line, Paradox is performing a translocal practice. The term amorphous may then extend not only to the arrangement of components in the circuit, but also the combination of languages on the label. By looking at Paradox’s own take on the Fuzz Face circuit we engage in “cross-cultural studies of the use of electronic music technology and instruments” (Bakan et al).

Here, language and material are imbricated. Symbolic language becomes concrete the moment circuit boards are printed and enclosures are painted. While critical linguistics accounts for the usage of English in localities, many times spoken, codified, and appropriated, the practice I am interested in is materialized in metal, paint, printed, and online text. During this process of materialization is when I consider English to become part of the interface of the instrument. Peter Paul Verbeek, a science and technology studies scholar, employs the term material hermeneutics as a framework for studying relationships between humans and technological objects. Verbeek derives this term from the ideas of Don Ihde, specifically hermeneutic relations. Hermeneutic relations describe how humans and technological artifacts engage with each other. Material Hermeneutics allows for a more robust schema or network in the Latourian sense, to differentiate more inclusive elements of technological mediation as actants. I consider this study to be in line with Actor-Network Theory as I unpack and reconfigure ideas commonly taken as given in the study of EMIs. The concept of interface or the concept of accessibility require reassessment the moment the pervasiveness of English comes into play.

Returning to the use of the term amorphous, a word used to describe something shapeless or with no clearly defined boundaries, I interpret this as a necessary descriptive act that allows ambivalence for an act that has little precedent in the global market of effect pedals: marketing from a country whose national identity does not read as technologically proficient.

Translanguaging and Translation

In 2021, five years after the Fuzz-e Cat, Paradox released a pedal called Carmesí. The pedal is an *all-pass phase modulator*, a more complex circuit than a fuzz pedal, usually requiring more functions and knobs. The Carmesí's interface consists of six variable knobs and two switches all labeled in Spanish. One of the buttons, "sendero," enables an envelope follower processed by a sample and hold function. This feature of the pedal essentially traces the path of the signal that comes in and creates a new one based on conditional functions afforded by the circuit. The word "sendero" means path and it's most commonly used to describe a hiking trail or a route rather than a single path in electronics. In the context of the Carmesí, it is a pedal that has been highly conceptualized both in function and design.

Figure 2

Carmesí effect pedal

Note. [Carmesí front panel]. Paradox Effects. https://paradoxeffects.com/products/carmesi

On the Paradox Effects website, they include the following tagline: "IN THE HYPNOTIC DESERT, A CRIMSON EYE AWAITS, They say that in the hypnotic desert, between the hot sand and delirium, you can find a crimson eye that hides a mystery" (Paradox Effects, 2021).

As an EMI, Carmesí is an effect pedal that allows the user to sculpt sound by running an audio signal through its circuit, but by using creative and imaginary narratives, they enlist what James Mooney and Trevor Pinch described as a "sonic imaginary" in the article "Sonic Imaginaries: How Hugh Davies and David Van Koevering Performed Electronic Music's Future" (Mooney & Pinch, 2021). Their definition of sonic imaginaries presents it as "a way of imagining and bringing forth a shared sonic world or experience grounded in technology, institutions, and networks'' (2021). I argue that the term "sendero," which is both unconventional for labeling an electronic device and foreing to the effect pedal market, prioritized the sonic imaginary of Carmesí, rather than its technological affordances.

From the time that Paradox began to market their guitar pedals locally in Tijuana to now having distribution in various international markets and counting professional musicians as users, the company's slogan has shifted to "Un Lenguaje Sónico," or a sonic language. In one of our conversations Castro commented, "Yes we make overdrives, fuzzes, and whatnot, but we are working with technological tools to be creative" (E. Castro personal communication, January 2021). This is an important distinction that shows how creativity has become an important marker for Paradox Effects in the global marketplace. Paradox now labels their devices in Spanish, but continues to market on their website in English. I argue that this deliberate combination of both languages for very specific purposes sheds light on the fluidity of globalization. Language printed on the label's interface does not affect its functionality, but shapes its interface. On the other hand, in marketing materials English continues to take precedent in the global marketplace.

Case Study 2: Bocuma

Bocuma is a synthesizer company from Guadalajara, Mexico founded by Emmanuel Galvan. I was made aware of their existence through an exhibition of Mexican musical technology organized by Paradox Effects in Tijuana in 2021. Galván's background is also in electronic engineering, and like Castro, it was easy for him to work with EMI circuits. Bocuma's website currently offers a build-your-own kit for a pocket-sized synthesizer and its flagship product, the Esquivel, a state variable filter built in Eurorack format for modular synthesizer systems.

The Esquivel is a well constructed state variable filter module with a very minimal and clean design. Eurorack format is substantially smaller and does not lend itself for larger fonts or illustrations like a guitar pedal. Bocuma has released two different versions of the Esquivel filter and looking specifically at the labels of both versions, V1 and V2, we find that there was a change in the language of one of the functions. In V1 the *cutoff* frequency knob was originally labeled with the word "cutoff" and in V2 it now shows a pictogram of a small graph illustrating the cutoff frequency.

Figure 3

Bocuma "Esquivel" State-Variable Filter Module Esquivel Front Panels

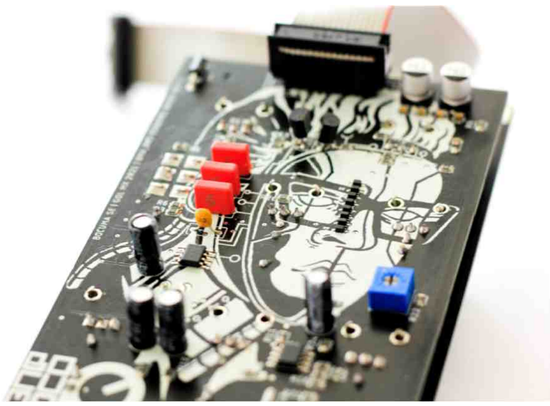
Note. [Esquivel faceplates V1 and V2]. Bocuma. www.bocuma.mx/product/esquivel

During an interview I conducted with Galvan I asked him about Bocuma's decision to change the label. He responded: "I never considered language as part of the design process, but coincidentally I have been shifting to symbols or abbreviations of words to avoid using strictly English in my designs" (E. Galvan personal communication, February 4th, 2021). While Galvan does not take issue with using English when necessary, English on the label creates some tension. In this sense, the translanguaging act becomes a gradual process and the pictogram provides a neutral language that avoids the task of translating into Spanish, creating a new term, and educating their potential customers on its meaning. The manner in which the pictogram reads as neutral to Galvan, in the same manner that English did due to its pervasiveness in the global market, brings up questions of whether English has any other functional use beyond a common language to communicate in.

The filter takes its name from Mexican space-age pop composer and innovator Juan García Esquivel. His musical legacy in the genres of exotica, lounge, and space-age pop have made him into a national hero in Mexico and the rest of the world. While he may not be as well known with younger generations, for Galvan, he is a role model. Galvan stated that he draws inspiration from the composer not just because of his body of work, but also because he studied engineering. He then imagined how Esquivel's own engineering background may have contributed to his innovative approach to composing and recording using synthesizers. In our conversation Galvan mentioned that he was inspired to design a functional state-variable filter for performers and studio musicians, but inspired by the legacy of Esquivel. Eurorack modules are usually purchased separately and part of the reason to adopt this format is because they are modular, meaning that they can be used with other modules of the same format. On the reverse side of Esquivel's printed circuit board, Bocuma decided to print an illustration of Esquivel's face.

Figure 4

Esquivel illustration printed on circuit board



Note. [Esquivel module back panel]. Bocuma. www.bocuma.mx/product/esquivel

Because the filter is not tied to any particular method or technique used by Esquivel, I argue that the filter pays homage to an imagined or speculative narrative surrounding the composer. Printing his image in the back of the module becomes a symbolic gesture regarding the influence and presence of Esquivel in the design process. Because Bocuma is part of a new generation of EMI companies, by signaling Esquivel's exceptional career, the filter activates the epistemology of Mexican musical and technological innovation.

Conclusions

For the last few years, the maker community in Mexico has begun to build stronger platforms for collaboration. Inspired by the DIY ethos of the global English-speaking communities centered on EMIs, Mexican designers, educators, and musicians have shifted the conversation to Spanish or a blend of English and Spanish, and in some cases pictograms. Social media accounts like Eurorack en Español have emerged, offering tutorials in Spanish and working with synthesizer companies in the U.S. to translate manuals and technical sheets. Paradox has currently labeled all of their products in Spanish or abbreviated English and has changed their slogan to "Un Lenguaje Sónico," a sonic language, shifting from a functional forward design practice to one that allows sonic imaginaries to contribute to the ideation process. Paradox also organized the Exhibición de Tecnología Musical Mexicana (Mexican Musical Technology Exhibition) to encourage collaboration and dialogue among other national makers.

I argue that by performing close reads on EMIs, treating them as complex and robust networks of mediation and agency, we are able to parse out the ways in which language carries cultural hegemony that becomes consolidated into the material. Translanguaging offers us a unique perspective into the subjectivities of bilingual musicians and EMI designers, as well as the fluidity of global flows of information. By casting EMIs in a network that affords language agency within the interface and as a force that shapes imagination and marketability, it allows translanguaging acts the ability to become a site of knowledge rather than a consequence of globalization. Finally I'd like to cite Nick Millevoi's review of the Carmesí in the guitar magazine *Premier Guitar*, which I argue illustrates the othering effects of English to the non-fluent, from the perspective of an English speaker:

Paradox Effects are a Tijuana-based company whose pedals usually offer a tweaked take on traditional effects. Before I could dig into this pedal, I headed over to the Paradox site to translate the control names, which are in Spanish, before I could wrap my head around the controls. (Millevoi, 2021)

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KEAMS Annual Conference - Workshop

Submitted Title: Tárogató and Computer Music

by Dr. Mara Helmuth and Dr. Esther Lamneck

Description:

The Hungarian Tárogató in Collaborative Composition

Mara Helmuth and Esther Lamneck have enjoyed a long standing artistic collaboration and will discuss aspects of their collaborative compositions including Sound Dunes for tárogató and computer music, which will be performed during the Festival.

Dr. Lamneck will introduce the Hungarian Tárogató and discuss works which are representative of its role in electronic music. These collaborative compositions include:
"Tárogató" with Larry Austin,
"Quanti Di Luce e suono" (audio video) with Alfonso Belfiore,
"Concerto" with Cort Lippe,
"Construction" with Sergio Kafejian,
"Presence" (audio video) with Alejandro Colavita and Terry Flaxton;
"Irresistible Flux" and "Sound Dunes" with Mara Helmuth.

Dr. Helmuth uses and develops granular synthesis techniques to create timbral transformations, and will demonstrate using granular instruments in MaxMSP and the RTcmix language with the sound of the tárogató. She will also discuss timbral analysis, structured improvisation designs, multichannel composition strategies and interactive compositional processes with her collaborator in Irresistible Flux, Sound Dunes and a new work.

These pieces by Helmuth and Lamneck have been inspired by the exploration of the tárogató sound world, and its digital transformations.

Biographies:

Mara Helmuth has been enthusiastically involved with electronic and computer music composition and research for decades. Recent works include Racket Routes, for eight-channel audio, based on tennis sounds, Opening Spaces, for video, based on a Menger sponge model, Cold Brew, a graphic score for flute, clarinet and fixed media based on the coffee genome, Onsen: Hot Springs, for vibraphone and fixed media, and Tranquilarea, for virtual reality installation. She is currently Professor of Composition at College-Conservatory of Music, University of Cincinnati and director of its Center for Computer Music, where she developed a program of courses in computer music. Her music has been performed internationally at conferences, festivals and arts spaces, and is on recordings from PARMA, INNOVA, Fundamental Sounds, Centaur (CDCM), Open Space, Electronic Music Foundation and Everglade. She has collaborated extensively with performers including composer/clarinetist/tarogato virtuoso Esther Lamneck, vibraphonist Joseph Van Hassel, clarinetist Andrea Vos Rochefort, percussionist/composer Allen Otte, clarinetist Rebecca Danard and saxophonist/composer Rick VanMatre in works for instruments and electronics. Her research has involved wireless sensor networks and music, Internet2 improvisation and performance, and the RTcmix music programming language. She created two installations for the Sino-Nordic Arts Space in Beijing, one for the Teach and Tour Sojourners organization in Kampala, Uganda, and one in collaboration with CCM students. She curated the Sound and Video Anthology 2019 in the *Computer Music Journal* Issue 43:4 from MIT Press, with a downloadable three-concert collection of works by women composers. Her writings also include analyses of works by Annea Lockwood, Carla Scaletti and Barry Truax, and she has written about gender and computer music. She was on the International Computer Music Association board of directors or in officer positions for over a decade, serving as its newsletter editor, Vice President for Conferences and President. Her early work involved programming a granular synthesis application, *StochGran*, an interface to Cmix which compiled instruments in C, and fixed media compositions Mellipse and Dragon of the Nebula. She holds a D.M.A. from Columbia University, where she studied with Brad Garton, and earlier degrees from the University of Illinois at Urbana-Champaign. She also plays tennis and practices T'ai chi ch'uan.

Esther Lamneck, Clarinet and Tárogató

The New York Times calls Esther Lamneck “an astonishing virtuoso”. She has appeared as a soloist with major orchestras, with conductors such as Pierre Boulez, with renowned chamber music artists and an international roster of musicians from the new music improvisation scene. A versatile performer and an advocate of contemporary music, she is known for her work with electronic media including interactive arts, movement, dance and improvisation. Dr. Lamneck served for more than three decades, as full professor and artistic director of the NYUNME at NYU, Steinhard. She makes frequent solo appearances on clarinet and the tárogató at music festivals worldwide. Many of her solo and Duo CDs feature improvisation and electronic music and include *Cigar Smoke*, *Tárogató Constructions*, *Winds Of The Heart; Genoa Sound Cards, Stato Liquido*, etc. Her latest new music improvisation album, *Small Parts of a Garden* is available at, https://www.setoladimaiale.net/catalogue/view/SM4420. Computer Music Journal calls her “The consummate improvisor.” Recent release, *Sky Rings* for clarinet and electronic music on Neuma Records has received rave reviews: “Surrealistically Captivating Electronic Solo Clarinet Sounds from Esther Lamneck” New York Music Daily; “Esther Lamneck has fascinating chops and ideas” jazzweekly.com; OPDUVAL “The music on Sky Rings contains depth and tension and sounds adventurous. A beautiful Album.”

Tárogató Description 9/25/22

The Hungarian Tárogató has a unique and hauntingly beautiful sound. Although many centuries ago 'tarogato' referred to a double reed instrument which originated in the Middle East and was at times called an Eastern oboe or a Turkish pipe, the current form of the Tárogató was built in the latter part of the nineteenth century in Budapest. Gustav Mahler required the Tárogató for the performances at Vienna and Budapest of the Shepherd Boy's tune in the third act of Wagner's Tristan and Isolde.

The tárogató is a single reed woodwind instrument with a conical bore, (the shape of today's soprano saxophone) rather than the cylindrical bore of the clarinet family. The Hungarian Tárogató, which I play is an original Stowasser, which was manufactured in Budapest over one hundred years ago.

It is an unusual woodwind instrument in that it does not have an extensive role in western classical music. It is originally a folk instrument from the regions of Hungary and Romania. It uses fingerings which are similar to the oboe's and has a scale which is non-tempered. Since it was primarily a rustic instrument and taken up by folk or Gypsy musicians whose music is handed down aurally, there are few known works specifically written for the instrument from its past.

Sándor Burka, one of the Hungarian masters of the Tárogató left us with a few tapes and recordings of his interpretations of Hungarian folk songs. My study of the folk music of Hungary and Eastern Europe, has provided me with a rich source of material for the instrument. While my style of improvisation has also been influenced by the great improvisers of our day, in jazz and new music, my sound and performance of the Tárogató remains reminiscent of its heritage.

Much of the new music for the Tárogató has been composed for me because of the freedom of the instrument and because of the magnificent sound of the Tárogató. The instrument's aural tradition has led me to perform it in new music improvisation and electronic sound environments which provide me with the freedom to explore the instrument's sonic potential. The tárogató provides a rich sound, full of harmonics. This has allowed me to broaden the range of the instrument including another octave of high harmonic material above its standard range. Because of the key structure it is possible to explore glissandi throughout much of the body of the instrument. This provides the possibility of "new techniques" which are not possible to such an extent on the clarinet nor other woodwind instruments with extensive key mechanisms.

I have had the privilege of working with numerous composers throughout my career. The collaborations are a sort of To, For and From as Lawrence Fritts so described in his Musicometry II. I look forward to each new proposal as a joint adventure in sonic exploration towards the creation of new works for the Tárogató. (Esther Lamneck)

REFERENCE SHEET, TÁROGATÓ SOUND SAMPLES FOR KEAMS WORKSHOP MARA HELMUTH/ESTHER LAMNECK. (9/25/22)

ARRIVAL track 4 from
TRASFIURAZIONI tárogató
Esther Lamneck/Alejandro Colavita
CERO Records

TÁROGATÓ
Esther Lamneck/Larry Austin
From *TÁROGATÓ* ROMEO RECORDS
(including works by Robert Cogan, Dinu Ghezzo, Ron Mazurek, Dary John Mizelle, Robert Rowe)

PRESENCE. (Video)
Terry Flaxton, Esther Lamneck, Alejandro Colavita
https://www.seditionart.com/terry-flaxton/presence

Construção
Esther Lamneck/Sergio Kafejian
From *Tárogató Constructions in Live Electronics*, INNOVA RECORDS
(Including works by Alfonso Belfiore, Mara Helmuth, Cort Lippe
Paola Lopreiato, Jorge Sosa)

QUANTI DI LUCE E SOUNO
Alfonso Belfiore/Esther Lamneck
From *Tárogató Constructions in Live Electronics*, INNOVA Records
(Including works by Alfonso Belfiore, Mara Helmuth, Sergio Kafejian , Cort Lippe, Paola Lopreiato, Jorge Sosa)
Video. https://www.youtube.com/watch?v=genNiltoG3U

IRRESISTIBLE FLUX
Mara Helmuth/ Esther Lamneck
From *Tárogató Constructions in Live Electronics,* INNOVA Records
(Including works by Alfonso Belfiore, Mara Helmuth, Sergio Kafejian , Cort Lippe, Paola Lopreiato, Jorge Sosa)

Computer Aided Composition, Timbral Synthesis, & Electro-Acoustic Super-Instruments: An Exploration of Heaviness in Electro-Acoustic Chamber Music

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In his article 'Reigen seliger Geister' (On My Second String Quartet) (2004), Helmut Lachenmann used the term super-instrument to describe moments in his work where the string quartet is treated homophonically as a single "16-stringed sonic mechanism" through "unison sound and unison rustling, i.e. the synchronous multiplication or amplification of sound or noise" (2004, p. 62) and/or the "parallel deployment of tones greatly separated in sonic space" (2004, pp. 64). In my Masters Thesis composition "Tripping in the Horror Vacui" for amplified violin, amplified cello, and amplified piano with electronics, Lachenmann's idea of the super-instrument is extended with digital music technology and electro-acoustic tools such as computer aided composition, timbral synthesis, live processing, and multichannel spatialization. By utilizing computer aided composition, the composer/author derived pitch information from noisy samples of raw data sonfications used in the work's fixed media/"tape track". This pitch material derived from the raw data sonifications in the fixed media is then mapped to the performer's instrumental writing to create homophonic textures. The material between the performers and the fixed media is then synthesized in the performance space with either a stereo or 7.1 multichannel speaker setup to create a huge and distorted electro-acoustic super-instrument. Creating these electro-acoustic super-instruments in my own works allows me to sculpt enormous melodic gestures that stretch out over the multichannel speaker setup thus also incorporating the "parallel deployment of tones greatly separated in sonic space" (2004, pp. 64). In Tripping in The Horror Vacui, these larger-than-life electro-acoustic super-instruments embody a maximalist aesthetic to create a heavy and sublime experience that overwhelms the audience through metal music tropes, density, intensity, and amplitude.

Keywords: Electro-Acoustic Super-Instruments, Computer Aided Composition, Synthesis, Multichannel Spatialization, Noise, Metal Music

Introduction

In his article '*Reigen seliger Geister*' (On My Second String Quartet), Helmut Lachenmann uses the term super-instrument to describe the orchestral technique of combining multiple instrumental voices into a single sonic entity. This orchestral technique has been explored by composers throughout music history. Prominent examples from the 20-21st Century include Louis Andriessen's *Worker's Union* (1975) where "everybody (the performer's/ensemble) plays in unison throughout: one voice united in delivering the same emphatic message unified in their intent" (Philip, 2020). When analyzing Unsuk Chin's *Double Concerto*, Jong Eun Lee states that Chin "is more concerned with melding the timbres of the percussion and piano soloists, along with that of the ensemble into a composite 'super instrument'— or, as she designated it recently, a 'hyper-instrument'—than she is with creating a vehicle for virtuosity of the soloists" (2014, pp. 3). Greenberg (2017) describes a similar effect in Chaya Czerowin's work *Sahaf* (2017) which features a climax where the ensemble becomes an "enlarged ratchet" via this same orchestration technique.

The possibilities for creating electro-acoustic super-instruments/hyper-instruments are endless as can be seen by the instruments showcased at conferences like New Interfaces for Music Expression (NIME) and National Association of Music Merchants (NAMM). For example, Tod Machover creates what he refers to as hyper-instruments through the augmentation of acoustic instruments with digital extensions to "give extra power and finesse to virtuosic performers" via live electronic processing (Machover n.d.). Other examples can be seen in more commercialized instruments like Re.Corder and the Akai Electronic Wind Instrument (EWI). Although Kallionpää and Gasselseder initially state that live electronic processing distinguishes "a true super instrument from other situations where a fixed media background is being used" (2015, pp. 2) they settle on a less precise definition: "a super instrument, or a super instrument composition, should be defined as an entity in which all the instrumental lines or computer-generated features complete each other in a manner which does not allow them to form separate identities, but to form an organic unity with its own congruent identity" (2015, pp. 7). This definition together with Lachenmann's conception of the super-instrument as an orchestral technique forms the basis of how I conceived of the electro-acoustic super-instruments in my Masters Thesis work *Tripping in the Horror Vacui* (2022).

Tripping in The Horror Vacui (2022) is a piece for amplified violin, amplified cello, and amplified piano with electronics (stereo or 7.1 multichannel speaker set up) that explores the concepts and aesthetics of heaviness. Here, heaviness relates to the composer's interest in contemporary metal music, noise music, and both acoustic and electroacoustic experimental/avant-garde concert music. In this work, heaviness is manifested musically through electro-acoustic super-instruments, noise masses, crushing drones, and complex metal inspired riffs and rhythms.

Heaviness

Heaviness in music means many things to different people. It can be used to refer to the literal material of the music as well as the metaphorical expressive elements of the music. *Tripping in the Horror Vacui* seeks to explore "the material references of 'heavy' timbres" and the idea that "heaviness is the music's perceived size, weight and density" (Hannan, 2018, pp. 9). Calder Hannan connects rhythmic complexity to heaviness as well as the idea that "compositional choices (not just timbral or textural choices, and beyond surface-level, melodic and harmonic ones) can contribute to heaviness by enacting metaphors for both the material and the expressive dimensions of 'heaviness'" (2018, pp. 10). Finally, heaviness is maximized through a metal music and noise music aesthetic.

The idea of heaviness as a music's perceived size, weight, and density lends itself well to theories on excess, maximalism, and Kant's aesthetic philosophy on the sublime (Demers, 2010). When discussing maximalist noise and drone music, Joanna Demers states that "sublime objects are impossible to encase within a frame because of their sheer scale. They inspire within the viewer a sober respect of awe that Kant describes as a 'negative pleasure,' whereas beautiful objects elicit unambiguous pleasure thanks to their adherence to perfect, universally recognizable forms" (2010, pp. 12). The work therefore also achieves this metaphorical heaviness through the creation of huge and sublime musical objects

Working Methods

When beginning *Tripping in the Horror Vacui,* I took a "sound up" compositional approach that began by layering sounds and improvising in the studio. This writing process brought forth the form, gestures, melodic material, spectromorphological changes, and heavy timbres that were injected into the written parts for the performers and their acoustic instruments. Because much of the groundwork for the piece was created through improvisation in the studio, and because I would add to the music sequentially, the generated form was through-composed and intuitive.

The starting point for the instrumental writing began with superimposing a harmonic scheme to ground the fixed media. The fixed media does not adhere to any harmonic scheme and is more freely composed in terms of melodic and harmonic material (Figure 1.). I chose to start the harmonic scheme on C because the first electronic gesture I created consisted of a low C drone and I wanted to pair this sound with the sound of bowing the string wrapping of the cello. New pitches are gradually introduced until the final section when all pitches are available to the performers. The black line around the MIDI roll is a tracing of the performer's written pitches which illustrates the tessitura of the harmonic scheme and how harmonic width is being utilized throughout the work. Inspired by maximalist composers like Varese and Penderecki I composed the music in large chunks which can be seen by the formal diagram below.

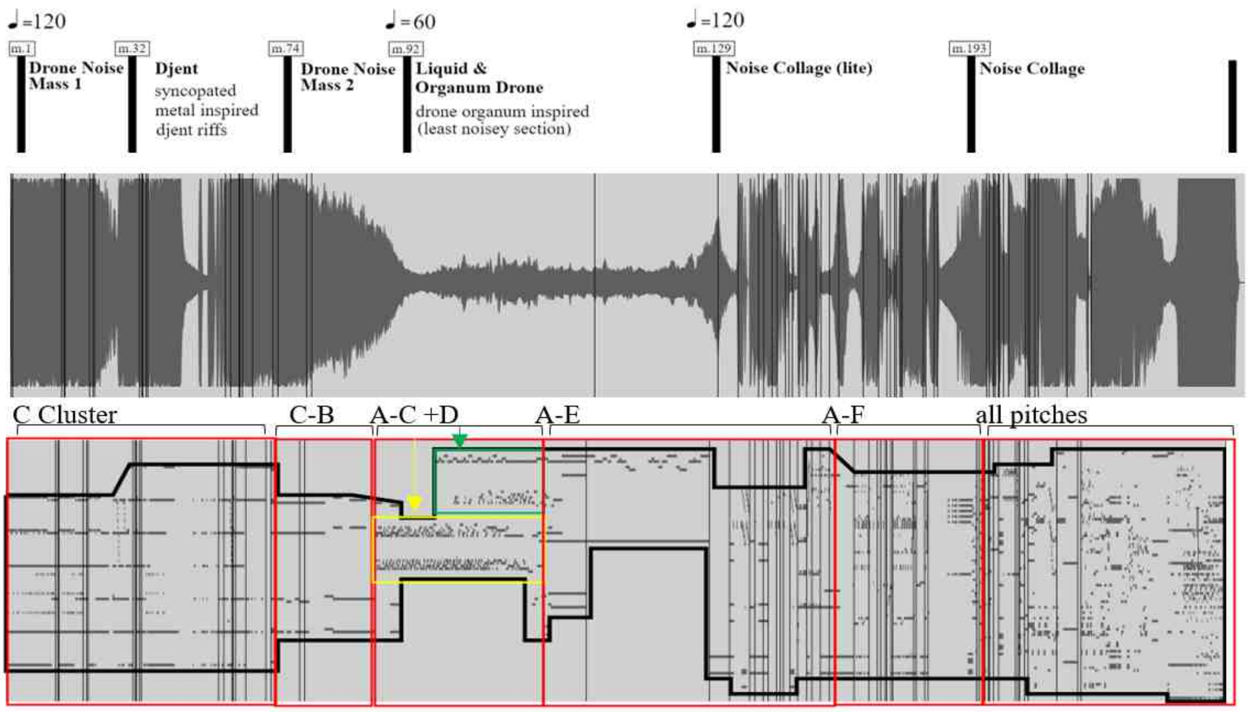

Figure 1. Formal Diagram of *Tripping in The Horror Vacui* (from top: section titles, waveform of performance recording, the progression from two pitches to all pitches, and MIDI roll of the performers written pitches.

Electronics

The electronic components of *Tripping in the Horror Vacui* consist of fixed media that the performers synchronize with via a click track routed to individual headphones. In performance, the violin, cello, and piano are amplified and processed with distortion, delay, and reverb using stock plug-ins in the Digital Audio Workstation (DAW) program Reaper. Using stock plug-ins will ideally create a work with accessible electronics. This processing is automated so that it starts, stops, and evolves in conjunction with the fixed media without the need for triggering by the performer. The fixed media and click track is also handled in the same Reaper session as the live automated processing. The textures fixed media combined with amplified and processed instruments and the spatialized gestures creates convincing electro-acoustic ensemble that is powerful and musically expressive. Figure 2 illustrates the signal flow path in the *Tripping in the Horror Vacui* performance setup.

Computer Aided Composition

For the climax of *Tripping In The Horror Vacui,* I used various samples of noisy raw data sonifications that are arranged together to create a *Noise Collage* (the final sections title). Raw data sonification (also sometimes referred to as data bending) "is the use of representations of data through sound, involving a mapping process into the aural realm" (EARS 2020). To create the instrumental's written music for the *Noise Collage* section, I used simple computer aided composition in Reaper. With Reaper's "record MIDI output mode", I was able to extract pitch information from the raw data sonifications and record it in the form of MIDI information. This pitch material extracted from the raw data sonifications in the fixed media is then doubled in the performer's instrumental writing to create massive electro-acoustic super-instruments.

When extracting the MIDI information, the pitched material in the raw data sonification moves very quickly, is extremely complex, and often is unplayable by humans. To create a convincing electro-acoustic super-instrument, I manually quantized some of the melodic gestures from the raw data sonification samples to the click track grid to make the instrumental writing rhythmically feasible for the performers. Samples that were not fixed to the grid created a more compositionally free scenario where I would pick and choose the notes and rhythmic structures that were most important and could most easily be transferred to the instrumental writing. This allows space to create melodic material that while taken from the raw data sonfication is not a direct transcription.

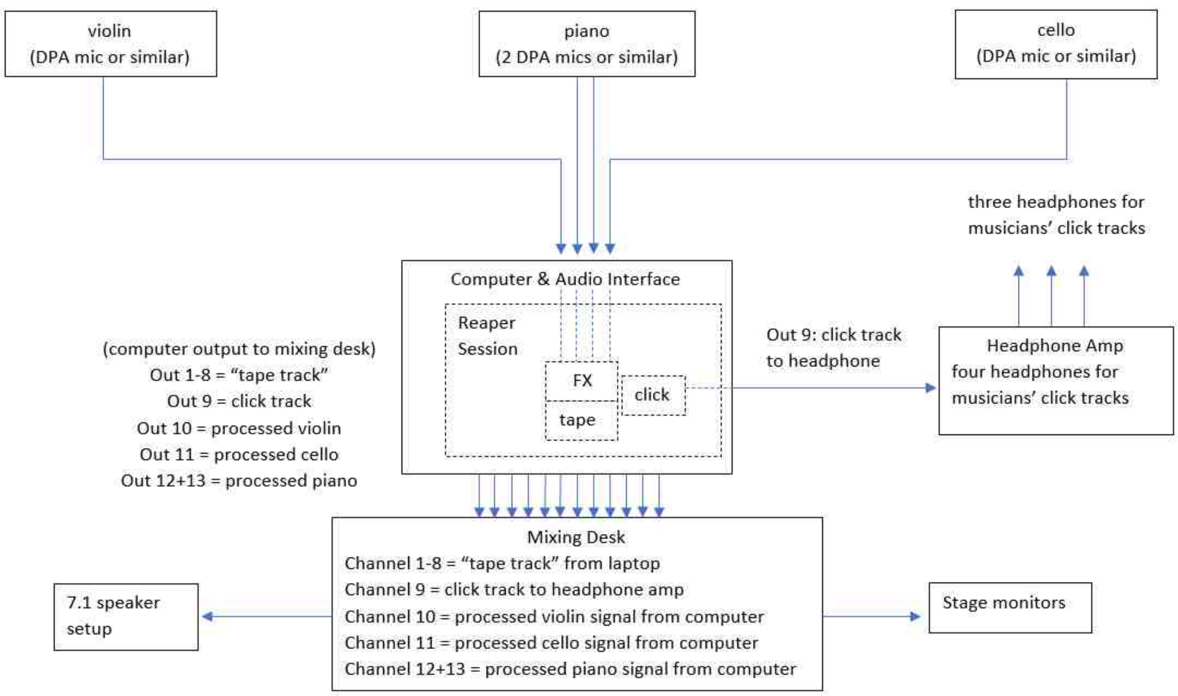

Figure 2. Electronics signal flow patch for *Tripping in The Horror Vacui*

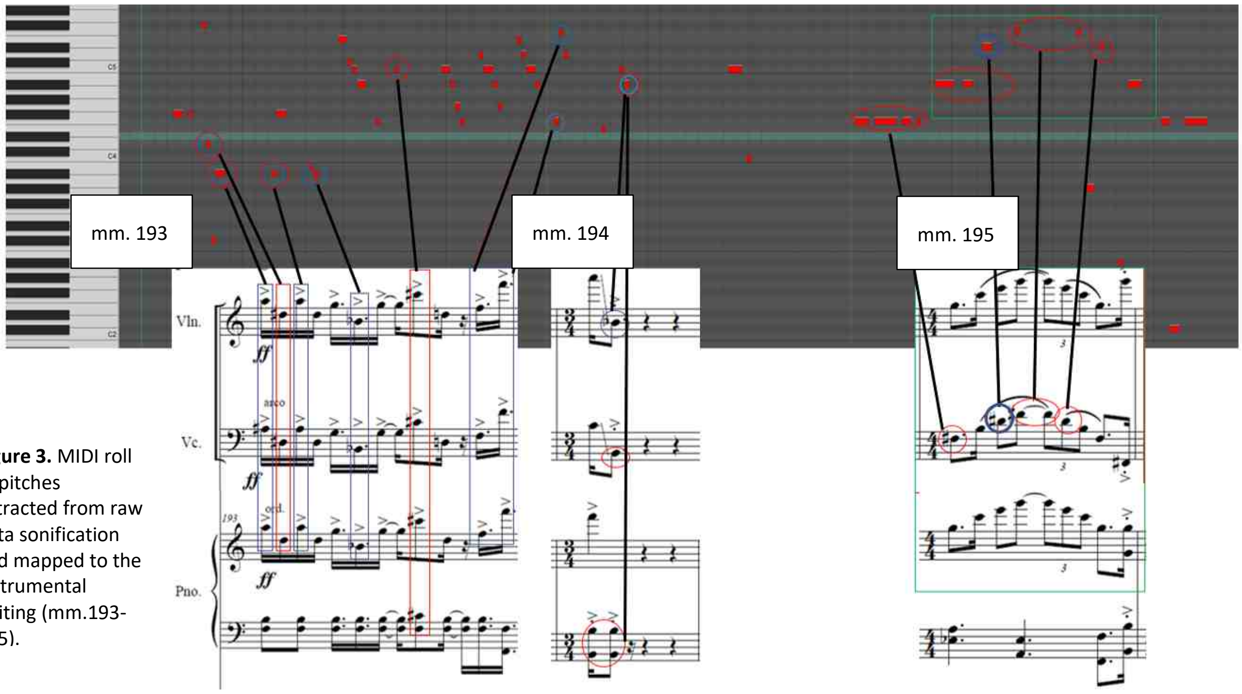

Figure 3. MIDI roll of pitches extracted from raw data sonification and mapped to the instrumental writing (mm.193-195).

Figure 3 shows the MIDI information that was extracted from three different raw data sonification samples, each lasting roughly one measure (mm. 193-195). The blue circles denote pitches that are direct transpositions from the raw data sonifications while the red circles denote pitches that are harmonized (usually in 2nds) against the MIDI information derived from the raw data sonfication (notes with both blue and red circles indicate a direct transposition as well as a harmonized note). The green rectangle around the MIDI information used in mm. 195 is an example of a pitched gesture in the raw data sonification that has a clearer and simpler melodic motif with less notes making it easily playable by the performers.

Figure 4 (mm. 219-224) shows a raw data sonification where the only real distinguishable MIDI information comes at the end of the gesture (F5 in blue circles and squares) despite the audio from the raw data sonifications being full of pitched material. Because the pitched information is moving too fast and sporadically, the computer assisted composition tools used to extract the MIDI information only gathers approximately 5% of the actual pitched content in the raw data sonification samples. In this situation I took a more traditional transcription approach and listened to the sample and analysed the audio file waveforms to compose gestures that matched the raw data sonification sample in a convincing way.

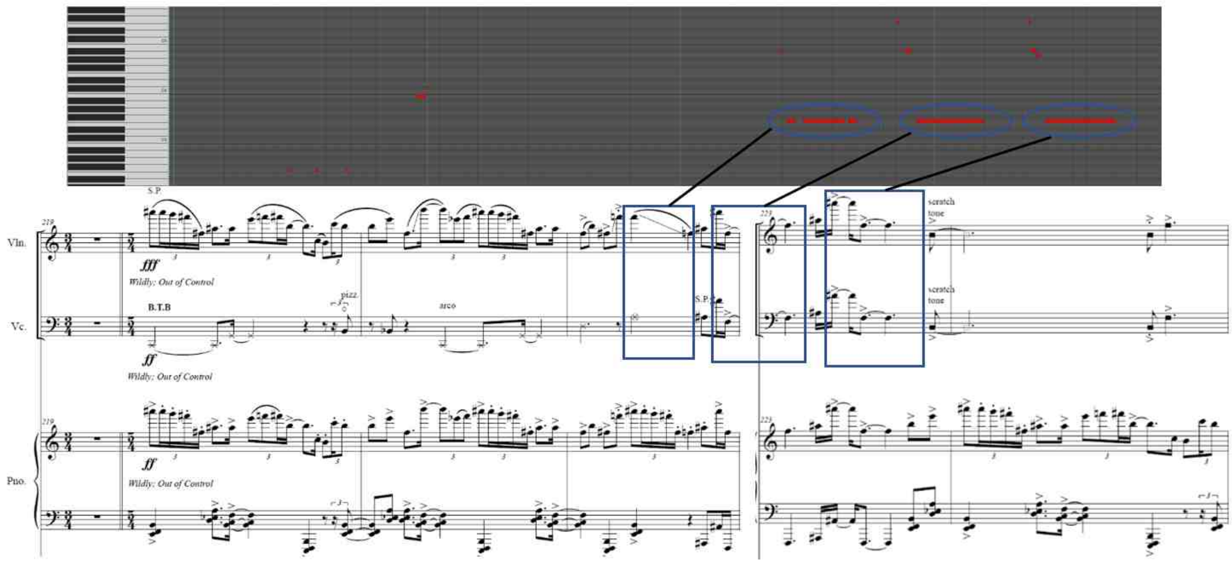

Figure 4. MIDI roll of pitches extracted from raw data sonification and mapped to the instrumental writing (mm.219-224).

Although there are far more advanced computer assisted composition tools available like OpenMusic(https://openmusic-project.github.io/) and Orchidea (http://www.orch-idea.org/) that can automatically orchestrate sound files, because the pitched material in the raw data sonification samples is so fast and complex, these programs would have still likely produced unplayable results. Therefore, the simple and flexible workflow of the "record MIDI out function" was preferable because of the orchestral freedom it allowed me. Using the MIDI information derived from the raw data sonification melodic gestures illustrates a new and exciting way to create electro-acoustic super-instruments. Taking this "sound-up" approach to composing for electro-acoustic ensemble where the synthesis of electronic and acoustic sounds becomes one giant composite gestalt is an almost constant presence throughout the work and contributes greatly to the perceived heavy aesthetic.

Source Bonding and Timbral Synthesis

In *Tripping in the Horror Vacui*, the violin, cello and piano are all amplified and processed with distortion, delay, and reverb throughout the piece to bring the instrument's timbres to the same plane as the fixed media. In the 7.1 speaker setup (Figure 5), using the three front speakers (Left, Centre, and Right) onstage and behind the performers as localized sources for their amplification and processing creates a more convincing electro-acoustic super-instrument. The fixed media is therefore the main vehicle for the spatialized gestures in the multi-channel set up. When played through the loudspeakers in a performance space, the live processing of the acoustic instruments and the fixed media fuse together via "source bonding" (Smalley, 1994) where listeners group the fixed and live sounds because they are emitting from the same sound source. This source bonding is of course amplified through the use of the homophonic textures between the electronic and acoustic voices.

For example, the second section of the work is based on the metal style known as Djent which is characterized by rhythmic complexity, and distorted, low tuned guitars (Bowcott 2011). This section was created using similar rhythmic complexity and samples of distorted electric guitar which operates as the most recognizable signifier of heaviness in Djent and metal music. During this section all the live instruments are distorted with the Reaper plugin WaveForm Distortion and the ReaXComp compressor plugin synthesizing their timbres with the guitar samples in the fixed media. Both the live and fixed elements play a C microtonal cluster to create a massive electro-acoustic super-instrument playing heavy unison gestures that showcases rhythmically difficult playing as can be seen in Figure 6. As Hannan states "rhythmic difficulty enhances 'heaviness' through various enactments of sonic metaphors for size, weight, density, power" (2018, pp. 4).

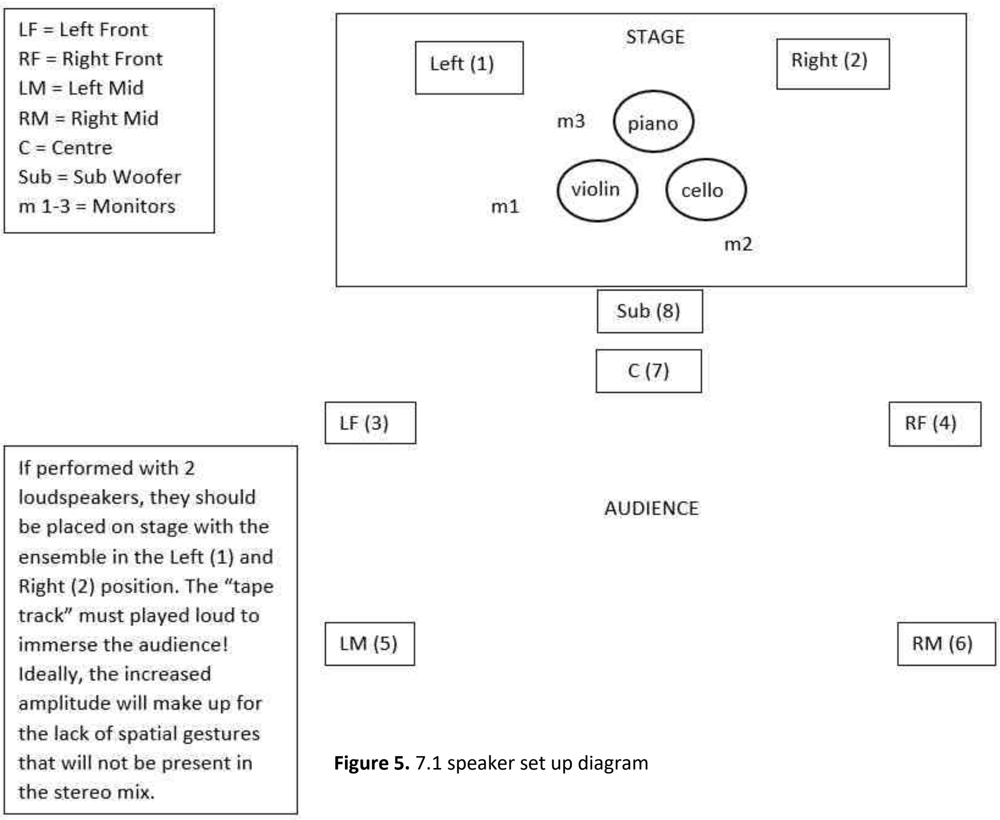

Figure 5. 7.1 speaker set up diagram

Figure 6. Beginning of Djent section

Spatialization

The piece is written for either a stereo speaker set up or 7.1 speaker setup. The intention of this speaker setup is to ideally subsume and overwhelm the audience with sound. Because much of *Tripping in The Horror Vacui* is an exploration in heaviness and density through difficult unison rhythms I had to find ways to create interesting, spatialized gestures without losing the clarity and precision of the music.

In the opening section, *Noise Drone Mass*, the spatialization can be heard in tension and release of noise with a sweeping raw data sonification and inharmonicity with high sine tones with slow wide vibrato. In this opening section there are three large noise drone gestures. In the first gesture a raw data sonification sample moves from the Centre (7), Right (2) and Right Front (4) speakers diagonally and back into the Left Front (3) and Left Mid (5) speaker (Figure 7.) This spatialized movement makes it

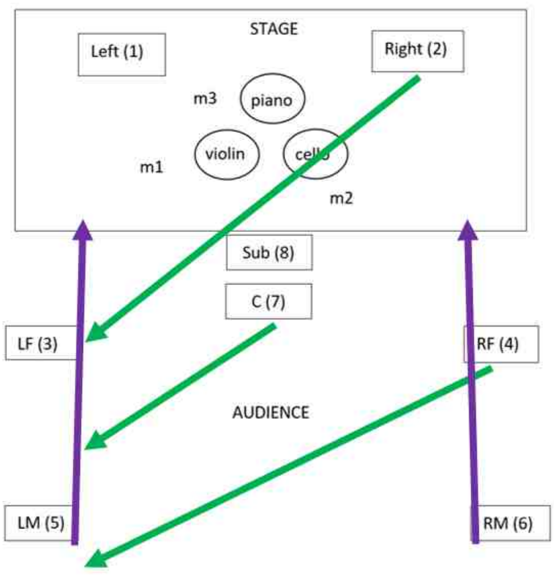

Figure 7. Spatialization pattern for the first drone gesture in the opening section *Noise Mass Drone*

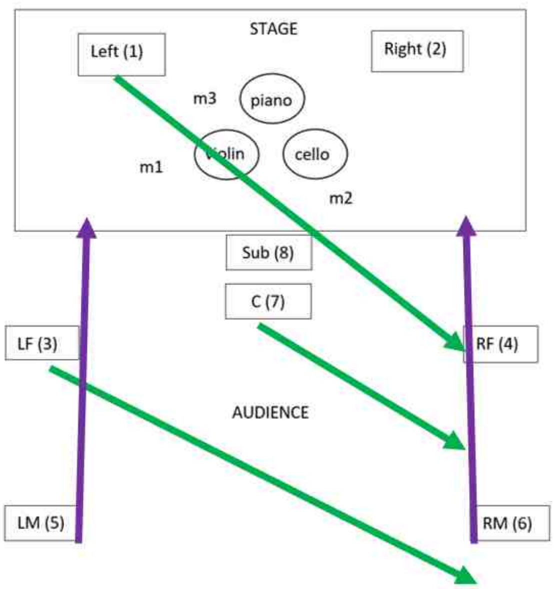

Figure 8. Spatialization pattern for the second drone gesture in the opening section *Noise Mass Drone*

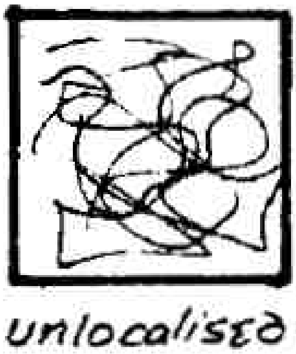

Figure 9. Unlocalized spatialization pattern from *On Sonic Art*

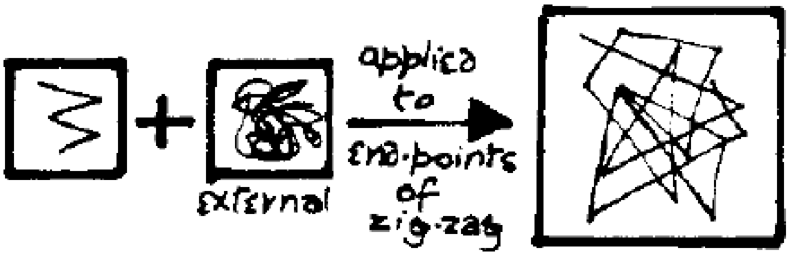

Figure 10. Unlocalized zig-zag pattern from *On Sonic Art*

feel as though something is flying over the listener from front to back, receding, and fading away. As the raw data sonification gesture ends it dovetails with the high sine tones which crescendo from the Right Mid (5) and Left Mid (6) speakers straight across the speaker array to the Centre (7), Left (1), and Right (2) speakers. The second drone noise mass gesture (Figure 8.) uses the same spatialization but begins and ends on opposite sides beginning in the Centre (7), Left (1), and Left Front (3) speakers before moving back diagonally to the Right Front (4) and Right Mid (6) speakers**.** On the third drone noise mass gesture of the opening section, the raw data sonification sample disappears and listeners are left with transient clicks and snaps that swirl and bounce around the listener in an irregular unlocalized motion inspired by Trevor Wishart's diagram from *On Sonic Art* (1996) (Figure 9).

The Djent section is an example of a section that requires precise rhythmic unison and homophonic textures to create an electro-acoustic super-instrument. More overt spatialization can be heard in the 8-bit "sound effects" in the fixed media which jump randomly from speaker to speaker.

At the climax and subsequent ending of the Djent section, arpeggiated 8-bit samples, processed oboe and recorder play quick 16^{th} note rhythms (which are being imitated by the pianist's right hand) that are spatialized in rapid circular and back and forth motions to create an overwhelming flurry of jittering high frequencty pitches. Both these spatialization gestures were inspired by Wishart's diagram for "irregular zigzag motion" (Figure 10.).

During the final *Noise Collage* section there is even jumpier and faster irregular zigzag spatialized gestures in the fixed media. The different short melodic fragments present a situation that lends itself well to this type of unpredictable ping ponging around the space.

Conclusion

Electro-acoustic super-instruments can be achieved in a variety of ways. In this paper, I have illustrated how I use the more traditional acoustic orchestral techniques of creating a super-instrument combined with electro-acoustic tools and digital media to create a convincing electro-acoustic super-instrument in my work *Tripping in The Horror Vacui*. Electro-acoustic super-instruments offer the potential for further research and research creation projects focused on electro-acoustic timbral synthesis.

Further directions include a commission from the University of Toronto's TapiR Lab to compose a new work for percussion sextet and electronics. This work will be a more concise exploration of an electro-acoustic super-instrument that exclusively uses the computer aided composition technique of extracting melodic and rhythmic gestures from samples of raw data sonifications.

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Dr. Michael Lukaszuk

Generative Music and Instrumentality

1. Opening

"Computing is not about computers anymore. It is about living." Nicholas Negroponte, "Being Digital" (Negroponte 1996, 6)

Musicians have been generating material out of rule-based systems for some time. From the prevalent use of canon in the music of the Middle Ages and Renaissance, to the use of nested *colotomic* rhythmic cycles in Gamelan music, algorithmic processes hold a firm place in many approaches to creation and performance. In the late 20th century, the ability to store and produce audio using computer technologies affected a shift in which not only methodology, but also musical instruments themselves were becoming generative in nature. The way in which a musical instrument could become a collaborator by embracing the ability of computers to repeat tasks, produce behavoiurs, respond to user interaction and either embrace or reject haptic control challenged existing notions of performance practice and virtuosity that were centered on physical mastery. What makes these instruments of meta-creation distinct is the manner in which they often inhabit and emerge from technologies that we encounter quite frequently in our everyday lives—they are hiding in plain sight until used for musical purposes. The fact that websites and mobile phone apps can store and/or become instruments can be thought of as a creative response to the way computing has become ambient in many homes, and social or educational settings. A motivation for new artistic projects and casual interactions for the sake of personal enjoyment can imbue such technologies with the potential to facilitate musical expression.

Thinking about generative instruments can also be a productive activity for considering how digital music-making relates to power dynamics and the idea of digitality in culture. This kind of digital lutherie is a departure from the centuries old practice of crafting ornate musical instruments for the sole purpose of concert performance (see Image 1). We can situate this phenomenon by investigating how instruments have emerged from functional technologies

Figure 1. Scroll of an 18th century viol

have emerged from functional technologies in cultural contexts that predate or run alongside the evolution of the orchestral strings, winds, brass and keyboard instruments that came into being in and around the so-called *common-practice era* of Western art music. In this sense, the study of generative musical instruments can highlight issues of Eurocentricity in popular organological approaches. The manner in which non-classical traditions embrace the hazy boundaries between tool and instrument also opens possibilities for adopting meaningful approaches to classification that lead to an understanding of how generative music can in fact be "of instruments" –and why that is a point worth arguing. Generative music can respond to other regimes of musical practice, especially those found in academic music circles, in the way that its performance relies on a hybridization of new music notation (code and/or device user interface) with an oral tradition consisting learned digital gestures (e.g. swiping, tapping, typing). These instruments can also be viewed outside of music scholarship to consider the implications digitality in various cultural spaces. Media scholar Tania Bucher's 2018 book "If…then" discusses aspects of power and politics within commonplace algorithmic media such as Facebook and Google's search engine. In discussing algorithms on social media, Bucher emphasizes the "…significant role users have in reconfiguring the algorithmic spaces that they themselves inhabit." (Bucher 2018, 95) For example, using specific language that will cause the algorithm will distribute their post more broadly. MIT Media Lab founder Nicholas Negroponte echoes the significance of reconfiguration in his 1995 book "Being Digital," in which he argues that the "real opportunity comes from the digital artist providing the hooks for mutation and change." (Negroponte 1996, 224) **The purpose of this article is to consider how we design and interact with algorithmic media to encounter new generative musical instruments.**

This is also a worthwhile study for considering how software can be a source of knowledge dissemination in the arts. Media artist Olga Goriunova supports the cultural expressivity of code art by arguing "that software is a culture in its own right. And that code, as a language system, reflects at least two cultures, that is software and that of the coder's context." (Diamond 2013, 58) The emergence of research-creation as a scholarly outlet for artists has allowed for the documentation of electronic music in culture through the use of performances and recordings, but more work is needed to establish digital lutherie as an act of cultural participation and knowledge dissemination.

1.1 Why Instrumentality Matters

In his article "The Instrumentality of Music," musicologist Philip Alperson argues that "the moment an instrument becomes an instrument it is both musically and culturally situated." (Alperson 2008, 42) Alperson uses the example of Bob Dylan's infamous performance with electric guitar at the 1965 Newport Folk Festival to emphasize how instruments help us understand the taxonomy of musical genres and how instrumentality, as a concept, goes beyond the notion of a music being "of instruments" to show how instruments place music in relation to larger social and cultural trends. Dylan's use of the electric guitar with the song "Maggie's Farm" disrupted associations about authenticity in folk music to create links with rock and sixties counterculture. This event has rippled out to become a symbol of rebellion for other politically conscious artists –for example, a "heavy" version of the song was recorded as part of Rage Against the Machine's 2000 album "Renegades." Generative musical instruments affect shifts that challenge the distinction between tool and instrument in the use of creative technologies and reflect trends belonging to digital media across many fields and cultural spaces.

Musical mobile device apps, coding languages, software and simulations in virtual environments such as digital games can cross boundaries to become musical instruments. The devices that store these objects (e.g. phones, tablets, etc.) and can seem almost ubiquitous and often serve a more functional purpose in our everyday lives. Regardless of genre conventions or ideas of authenticity, and considering where these objects belong on the spectrum between instrument and tool can reveal positionalities about making music in a digital culture. In his book "Sonic Writing," computer scientist and musician Thor Magnusson writes on the unfolding of instruments out of such devices, discussing how "young people often enter the world of music through digital technologies such as apps and games..", (Magnusson 2018, 241) and how these digital systems become instruments through knowledge that is accumulated through their use in non-musical contexts. Magnusson also elaborates on the difficulties regarding the instrument vs. tool distinction as it relates to digital music instruments, writing that sound-making objects transition from tool to instrument in their ability to "constitute the meaning of their play through their expressive nature." (Magnusson 2018, 18) In other words, where a tool may be used for transmitting a message or facilitating a task, we can make the app or the code we write into musical instruments that are an "end in themselves." Non-classical traditions in particular support the idea that functional objects can adopt instrumental identities. The image below shows a contest for storytellers and musicians using the *ligawka*, a Polish folk instrument used to herd cattle. The way that this instrument can move between agriculture and entertainment makes a case for a mobile phone or included

Figure 2. A ligawka in a musicians contest in Bukowina Tatrzańska, Poland

app to oscillate between a communications device and an outlet for sonic experimentation. Computer musicians have explored the functional ontology of digital instruments, some of which having generative capabilities, in a way that highlights multiple identities for these objects. Ajay Kapur, whose work often blends robotics and traditional Indian music, writes about adding sensors to the body of the performer to extend of the instrument so that its possible status as a prized spiritual object is not violated through modification. The app "Air" by software designer and musician Peter Chilvers and Irish vocalist Sandra O'Neal uses automation and randomization to create evolving layers of vocal and instrumental samples that can be controlled or released automatically. One of the features of "Air" is the ability to create a kind of meta-instrument by connecting to other nearby speakers and devices. Here, the iPhone/iPad is an effective example of augmenting the idea of the mobile phone and tablet as devices for networked communication by allowing users to play, listen and interact with the software on multiple devices at the same time.

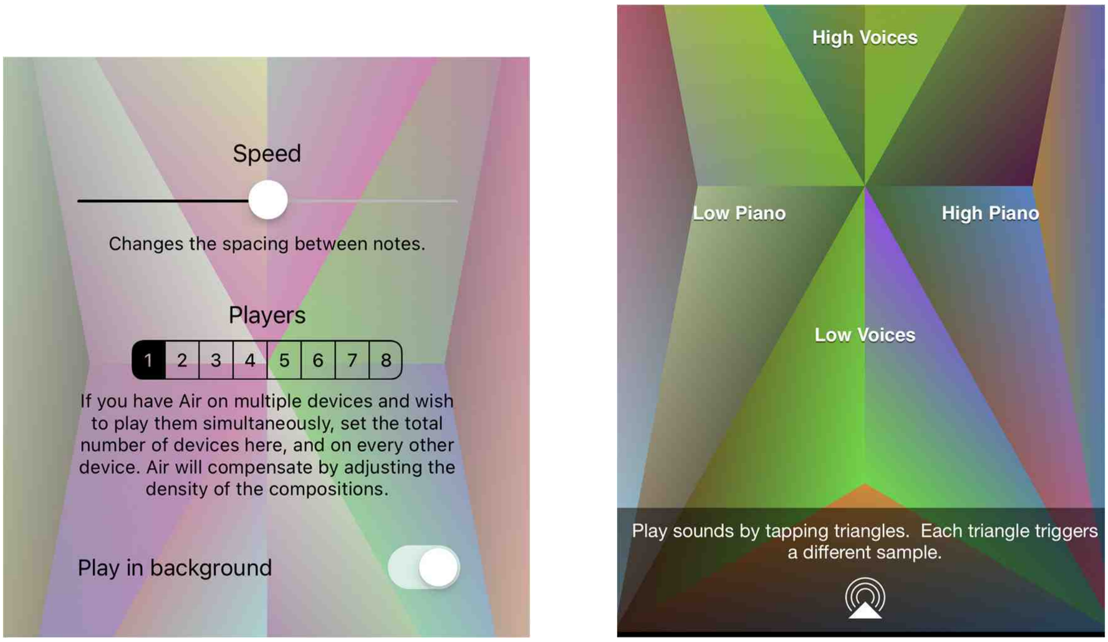

Figure 3A-3B. selections from "Air" user interface

"Air," represents of a shift in which digital media offers new ways for artists to disseminate their music without relying on typical formats such as album releases, radio play or streaming (which is digitally oriented in terms of its ability to store audio but still reliant on the fixed consumption of album tracks). In gaming, music rhythm games such as RedOctane's Guitar Hero series have produced interactive models for digital music consumption that sustain interest in songs through a goal-oriented or competition-based approach where users chase high scores and compete. An interactive mobile app instrument such as "Air" relies on a different kind of interactivity in which the artist's (i.e. Chilvers and O'Neal) contribution is the raw materials and the constraints of the instrument and the user accesses those materials to construct and modify generative processes. "Air" is distinct from Chilver's work on similar generative instruments such as his collaborations with Brian Eno to make the popular 2008 iPhone app "Bloom." These apps use synthetic or at least ambiguous sampled sounds to create a kind of *acousmatic* sound world in which there is intentional ambiguity with the manner in which the source material is presented (see the use of descriptors such as "impact" and "blend" in Figure 4). Conversely, "Air" relies on the reconfiguration of O'Neal's recorded vocal performance through gestural interaction with one's device. While making music with "Air," the player is not only reconfiguring algorithmic spaces (e.g. affecting looping behavoiurs and randomization), they are emphasizing the way in which gesture with digital technologies affirms digital instrumentality. In her PhD Dissertation, Vanessa Chang writes that "…through gesture, contemporary digital art practices borrow and recode forms of presences…to highlight a more diverse array of creative agencies." (Chang 2017, 20-21) A "vocal performance" with "Air" abandons the idea of the voice as a fixed instrument dependant on breath-control and becomes an expression of a cybernetic virtuosity that depends on feedback between physical and simulated bodies.

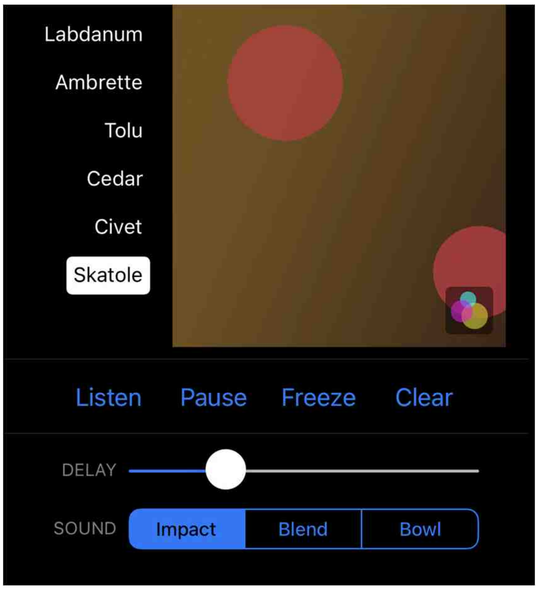

Figure 4: An excerpt from the “Bloom” user interface showing source sound choices

In his book “Understanding Digital Culture,” sociologist Vincent Miller presents a set of characteristics that define digital media: networked, interactive, hypertextual, automated and databased. (Miller 2011, 18) The framework used by Miller to suggest that digitality represents a paradigm shift from older forms of media can be applied to generative music instruments to understand how they suggest new ways of thinking about instrumentality that creates space for apps and the like. Aside from the natural capacity for networked communication in a mobile phone app such as “Air,” other kinds of generative electronic instruments also feature these characteristics to represent a range of genres and practices. In the 21st century, the laptop orchestra/ensemble has been a popular model for teaching electronic music at the post-secondary level. Many newly luthiered instruments for these ensembles contain networked communication to exchange musical parameters (e.g. effects settings) and even simply as a chat tool that can work in lieu of conventional musical notation (see bottom of Image 5). Michael Lukaszuk’s “Linear” is an instrument for solo or group improvisation that can be played using a laptop. The performer draws lines in a graphic display in which length, contour and thickness translate to sonic parameters such as frequency/perceived pitch-level and amplitude/perceived loudness. The instrument is generative in the sense that the user initiates a process in which the draw lines “loop” and later automatically drift from the drawn settings. How does this represent a paradigm shift from the more established instruments that we tend to experience in concert settings? Simply based on the sounds that result from strumming, blowing or striking, user-responsiveness seems to be part and parcel of most instruments. Miller calls on a definition of interactivity by Danish media theorist Jens Jensen which refers to “… media’s potential ability to let the user exert an influence on the context and/or form of the mediated communication.” (Miller 2011, 20) Jensen’s definition highlights the idea of interactivity as a spectrum and that some media, tools, or even musical instruments can influence practice in greater, or at least different ways. For example, the use of drawing in “Linear” introduces a kind of audiovisual feedback where changes to line parameters affect ongoing looping audio processes.

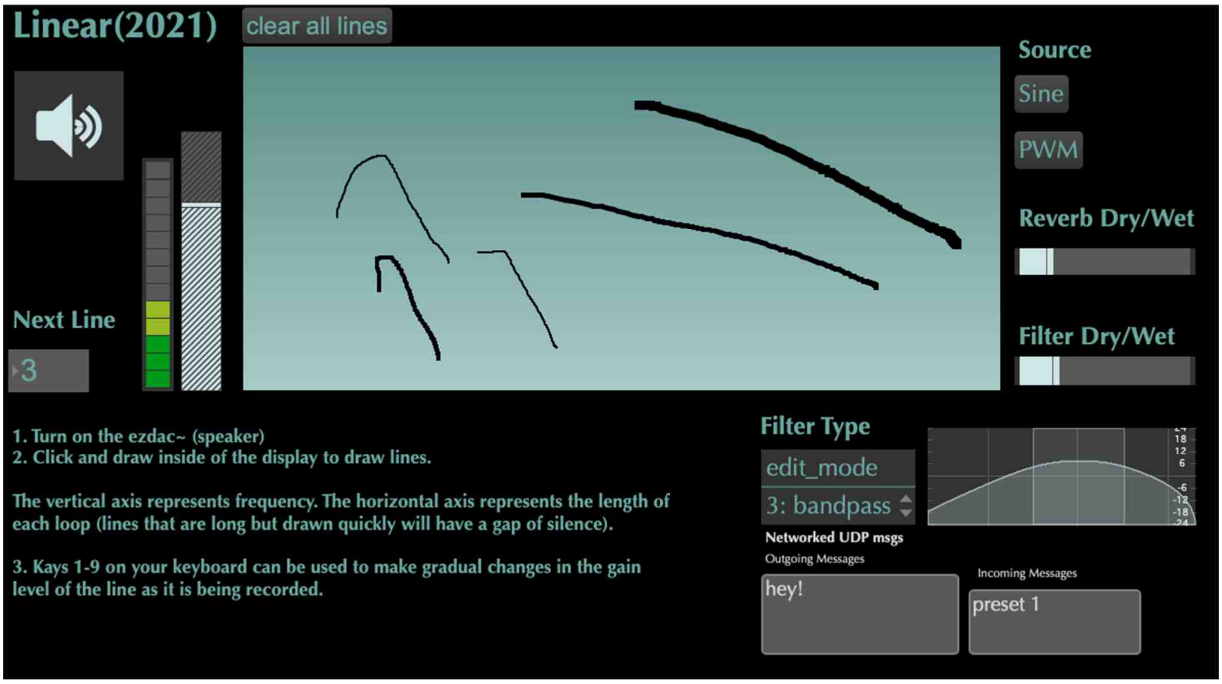

Figure 5. Interface for Michael Lukaszuk's "Linear" instrument for laptop improvisation

Miller describes hypertextuality as a content that "…combines traditional text with interactive branching to create a non-linear text." (Miller 2011, 21) Here, bringing generative electronic instruments into the fold, as compatible with Miller's model for digital media, requires an expansion of the idea of a text to include musical instruments. It is necessary to avoid taking aspects of design and construction for granted by viewing them as incidental to the process of obtaining an object for performance. Scholarship of non-classical traditions often involve a closer look into how building and modifying instruments works as an approach for documenting ideas about culture and identity. For example, ethnomusicologist Joshua Tucker's study of modern *chilili* (a Peruvian chordophone) shows how adaptations and modifications (e.g. the use of amplification, but also sourcing local tone woods) allow younger players to connect with unlived histories, and reflect new needs for cultural expression. (Tucker 2016, 338) In his writings on new media art, the Senegalese art historian Taki E'Bwenze argues that "technology redefines African experience at both local and the global levels, opening up the potential to sustain a relationship with current practice and the future." (Diamond 2008, 60) Being able to disrupt the present by projecting ideas about both the future and the past is in line the way that hypertextuality addresses linearality and authorship. In the case of generative musical instruments, this kind of "sonic writing" through digital lutherie can be viewed through instruments that rely on audio samples that bend time and genre, but also in the use of data for training musical systems as a means for multiple authorship.

Composer Arne Eigenfeldt's Generative Electronica Statistical Modelling Instrument (GESMI) produces electronic dance music in genres such as house and dubstep by analyzing a corpus of human-made transcriptions of existing tracks. The instrument can be considered autonomous in its capacity to make sounds without human intervention, but the act of transcribing musical parameters and the implicit bias that comes with such an activity can also be considered a kind of playing outside of real time. The transcription aspect is also what relates GESMI to Miller's proposed idea of hypertextuality in digital media. While the resultant EDM tracks produced by the instrument may be linear in nature, the manner in which the system draws on various transcribed elements is based on the use of probabilities to move between comparable sounding elements such as bass lines and drum patterns. In this case the “body” of the instrument is the material which GESMI learns, which is variable depending on the approach to transcription. While the use of conventional music notation may seem reductive for an analysis of music as rhythmically nuanced as EDM the prevalence of commercial sequencer tools in dance music carry the residue of meter and rhythmic groupings from Western music theory. Still, GESMI challenges paradigms belonging to EDM such as the links between genre and device, such as the association between acid house and the Roland TB-303 bass synthesizer, (Muggs 2016) by introducing an algorithmic alternative to a conventional hardware sequencer.

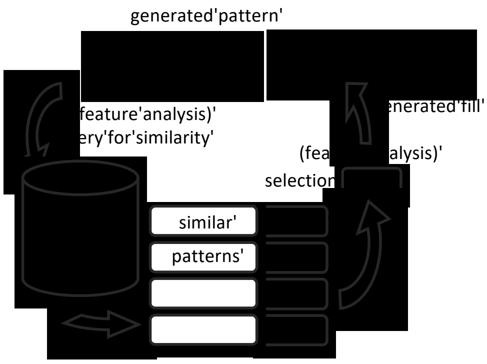

Figure 6. Example of transcription used for GESMI (Eigenfeldt 2013, 6)

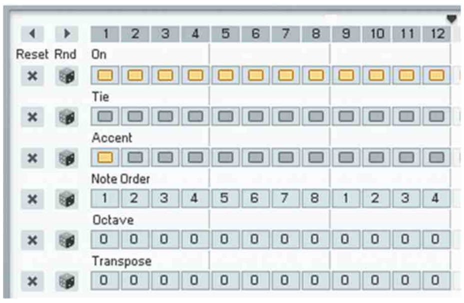

Figure 7. Example of sequencer from Native Instruments FM8 plugin

Miller’s discussion of automation focuses on the modeling of behaviours, using examples such as social media and web services provided by companies such as Amazon and Google to automatically generate individual profile pages for new users. (Miller 2011, 23) In music consumption through streaming, we see a fair amount of effort by services such as YouTube Music and Spotify to algorithmically predict listening behaviours and present recommendations. The way in which algorithmic media can create material specifically for users can be observed in generative musical instruments in their ability to spontaneously mould their bodies according to the behaviour player. In other words, of course the presence of algorithmic parameters in an instrument leads to a certain level of automation, but automation begins to carry real weight when paired with interactivity. In a study of user-curated music playlists on streaming platforms in relation to Foucault’s concept of *biopower*, researchers at Bilkent University show how even algorithmically generated playlists rely on continuous information exchange between multiple actors (algorithms, users, streaming specialists). (Karakayali & Alpertan 2021, 24) This work highlights that beyond the mere presence of automation, "redeployment" or resistance to an algorithmic system adds value to a system--- whether it be an artist recommendation or the evolution of patterns of pitch, rhythm or samples in a new work.

Open-source tools for music creation through coding allow for a kind of redeployment through continuous intervention through spontaneous lutherie. For example, the synthesized model of a Mandolin from the ChucK programming language allows the user to instantly affect changes

```
Control Change Numbers:
   - Body Size = 2
   - Pluck Position = 4
   - String Sustain = 11
   - String Detuning = 1
   - Microphone Position = 128

by Perry R. Cook and Gary P. Scavone, 1995 - 2002.
```

extends StkInstrument

(control parameters)

- **.bodySize** - (float , READ/WRITE) - *body size (percentage)*
- **.pluckPos** - (float , READ/WRITE) - *pluck position [0.0 - 1.0]*
- **.stringDamping** - (float , READ/WRITE) - *string damping [0.0 - 1.0]*
- **.stringDetune** - (float , READ/WRITE) - *detuning of string pair [0.0 - 1.0]*
- **.afterTouch** - (float , WRITE only) - *aftertouch (currently unsupported)*
- **.pluck** - (float , WRITE only) - *pluck instrument [0.0 - 1.0]*

Figure 8. Excerpt of functions list for Mandolin from ChucK programming language (Wang 2022)

parameters that amount to a smaller body size, the strength with which the string is plucked and timbral brightness or warmth that result from playing closer or further from the bridge of the simulated mandolin. The ability to continuously algorithmically reshape the simulated mandolin presents a challenge in which automation calls into question the importance of physical vs. simulated in understanding what makes an instrument. Automation can present ideas about instrumentality in generative music by compelling creators to consider what kind of gestures or modes of performance are germane to a digital instrument.

Finally, Miller's framework ends with the idea of digital media being databased –relying on a system that can flexibly store, retrieve and filter data. (Miller 2011, 24) The manner in which media such as websites sort through databases of text and image is comparable to those instruments such as Eigenfeldt's GESMI that rely on making decisions based on a corpus of user-inputted information such as musical analysis. Just as the user interface of a website presents a veneer of coherence while the system reacts to user input by navigating a database, such instruments can be perceived as coherent whole while in fact the main "body" lies in the stored data. Composer George E. Lewis' "Voyager" software is a good example of generative musical instruments pairing with the databased nature of digital media. While "Voyager" itself is not an instrument, the system adapts to established instruments such as synthesizers, samplers, and even certain concert instruments, such as the Yamaha Disklavier, an acoustic piano that is also capable of receiving MIDI messages from computers and digital audio devices. Instruments become generative through their pairing the software – its capacity to respond and create –Lewis describes the system as "a multi-instrumental player with its own instrument…" (Lewis 1993) Here, Lewis' work is databased in two ways: the choice of instrumentation that the system relies on, and the way that it analyzes and reacts to other performers.

There have been versions of “Voyager” that use large collections of MIDI versions traditional orchestral instruments combined with instruments from Africa, South America, East and South East Asia and the Middle East to form a virtual orchestra in which the makeup of sections is in a state of flux as the software recombines and silences parts (see Figure 9). In a 2005 interview with Bomb Magazine, Lewis relates the idea of having a large number of software players that could play any instrument at any time to his activities with the Chicago-based AACM (Association for the Advancement of Creative Musicians), which explored free improvisation in a way that broke down boundaries between jazz and experimental music according to their motto: “Great Black Music, Ancient to the Future." The AACM’s multi-instrumentalism was augmented in the software domain with the system’s occasional use of a large improvising orchestra. Lewis mentions: “I don’t know of any culture where you can get a hundred people together, each one of whom can play a hundred instruments, and they get together and they improvise” (Parker 2005, para.17) and that the political subtext to this setup is based on both an appreciation and the rerouting of the classical orchestra model.

The manner in which “Voyager” engages in dialogue with it’s co-performer(s) represents a kind of live databasing that also projects ideas about agency in improvisation. In his article “Interacting with latter- day musical Automata”, Lewis comments on the use of *nonmotivic* approach to form, instead describing a “state-based model” that uses a “global aggregation” of sonic information instead of a linear transformation of gesture, which he considers culturally situated in a Eurocentric mode of thinking about improvisation as being centered on a single melodic germ. Lewis also considers his development of a non-hierarchical system as a response to the manner in which narratives about mastery of control have shaped a computer music practice that is highly influenced by Eurocentric concert music perspectives, especially with its emphasis on the use of “controllers” – e.g. devices to control various sound-making parameters. He instead considers the possibility of “non-controllers, involvers or enablers.” (Lewis 1999, 108) The components collected for analysis in this state-based model are comprehensive in establishing details in the performance beyond what is typically done in many computer music pieces, which tends to focus on tracking the pitch of an instrument more so than any other parameter.

```
\ voyager.fth
\ load file for Voyager
\ Macintosh/Forthmacs/Moxie version (1993)
\ rev 1 20 93 gel UCSD

decimal

: voyager ; cr .( Loading voyager... )

12 constant nchans    \ # of instruments/midichannels
nchans 1 - constant maxchan \ highest channel

\ pitchset compiler and library
ld setcalc.fth        \ pitchset compiler
ld africa.fth         \ mbira, balafon
ld arabica.fth        \ arabic, persian
ld hinduset.fth       \ java, bali, india
ld hellenes.fth       \ "greek" sets
ld equality.fth       \ 12-tone equal temperament
ld meansets.fth       \ meantone sets, just, partch, etc.
ld fareast.fth        \ japanese, chinese
```

Figure 9. Excerpt of the original code for “Voyager” (Lewis 1993)

An effort to highlight generative electronic instruments as in fact possessing some sense of instrumentality emphasizes the wide range perspectives on how they can be played, and their value as both a component of and a tool for understanding digital culture. Situating these instruments as akin to digital media as a whole reveals a compelling interpretation of textuality in which artists and technologists write about sound in culture through digital instrumental bodies. In this way, these new musical instruments become a tool for the dissemination of what cultural theorist Stuart Hall describes as "conjunctional knowledge" –knowledge that is relevant to immediate cultural/political circumstances and acknowledging that the structures that form culture are instruments of power. (Hall 2007, 33)

1.2 Instrumentality in Earlier Electronic Music Practices

One of the important trajectories in the history of electronic music creation has been the motivation to draw connections to instruments within a sound world constructed using synthesis and recordings. Generative music can be viewed as another layer in a series of writings, technologies and musical works that represent an ongoing conversation about instrumentality for creatives and technologists. Jean Claude Risset, whose synthesized *Risset Bell* has arguably gained the status a trope in electroacoustic music, produced significant works such as "Mutations" (1969) that use percussion and brass-like sounds in a way that led to the idea of the model as a liminal space between authenticity and sonic experimentation. In commenting on instrumentality in his creative work, Risset said that the: "…palette of the computer would not be complete if it did not include those sounds which are very familiar, and which have proven their musical utility. In fact, the strong identity of instrumental timbres can be an anchor, a point of departure for journeys throughout timbre space." (Risset 2000) Work that took place through the 1970's and 1980's show how computer music innovation and compositional considerations about instrumentality developed in tandem.

John Chowning's 1973 Computer Music Journal article "The Synthesis of Complex Audio Spectra by Means of Frequency Modulation," which contains a large section titled "Simulation of Instrument Tones," presented frequency modulation synthesis as a computationally inexpensive means for producing sounds that appeared more realistic (e.g. nuanced and complex in terms of spectral content) than earlier work with analogue techniques. This can be heard in works that can be considered historical markers in electroacoustic music such as Chowning's 1981 piece "Phoné" which draws on FM emulations of the human voice. These FM synthesis innovations also resulted in patents licensed by major musical instrument manufacturers such as Casio, Korg, and most notably Yamaha. (Chowning 1975) Yamaha's adoption of FM synthesis led to many of the instrument emulation presets found in commercially available keyboard synthesizers such as the DX7. In her article "What Makes It Sound '80s?" music theorist Megan Lavengood describes the scope of the influence that Yamaha DX7 in the music of the 1980's, writing: "I precisely define an aspect of the '80s sound by focusing on one of its most important timbral contributors: the pervasive use, across many different '80s genres, of the Yamaha DX7 FM digital synthesizer." (Lavengood 2019, 74) Recently, the presence of software representations of the DX7 by major plugins manufacturers such as Native Instruments and Arturia have brought forth a new level of simulation in that work presented for timbral modeling can now be algorithmically controlled to automate other musical behaviours.

Composer Laurie Speigel's writings on her use of algorithmic approaches to computer music composition mention the importance of allusion and mimicry of process. Speigel's work acts as a link between instrumentality in fixed-media electronic music and the playing of algorithms to make generative music. In her chapter from "The Oxford Handbook on Algorithmic Music", Speigel writes: "Once written, an algorithm is essentially a structure external to its creator. In other words, it constitutes a new independent musical instrument or tool." (Speigel 2018) Rather than focusing on the recreation of complex instrumental timbres, albums such as Speigel's 1980 debut "The Expanding Universe" contain a sense of computer-generated improvisation in which tracks such as "Appalachian Grove" use unabashedly electronic sounds but still suggest the kind of modal improvisation found in American folk music. Speigel's effort as a composer and computer musician produced a way of thinking about instrumentality in earlier electronic music that was more comprehensive than many of her predecessors, even those working with complex methods such as physical modeling from acoustic analysis.

1.3 Classification of Instruments and a "Digital Oral Tradition"

The study of instruments through categorization and other forms of analysis helps us understand how lutherie works as a form of cultural participation. Including generative instruments as part of a new organology can help highlight cultural expressions that are germane to digital culture, and also show broader problems of instrument classification in music scholarship. In the 20th century, many systems of classification for instruments, at least in much of the Western discourse on this topic, consisted of variations on the 1914 text, "Classification of Musical Instruments" by Erich von Hornbostel and Curt Sachs. This used a top-down approach that focused on the physical materials that were needed to make or perform on an instrument. As electronic instruments were not in wide use around the time of its publication, it is understandable that these categories are dependent on the idea of an instrument as comprising an acoustic medium with vibrating bodies in a physical space (e.g. "chordophones" being instruments that produce sounds using vibrating strings). Mid-century attempts at responding to the emergence of new electronic instruments such as the Theremin and Ondes Martenot include the addition of an "electrophone" category to Hornbostel and Sachs' system, and a section on "Electric Instruments" in Sachs' 1940 book "The History of Musical Instruments." Sachs' additions do not really represent a good faith effort to integrate these early electronic instruments into the existing framework of idiophones, aerophones, and so on. Sachs includes an "Epilogue" section to his 1940 book, in which he writes: "…surely these instruments their existence to the experimentation of electro-engineers rather than any musical need." (Sachs 1940, 449)

In 2011, the cultural heritage organization Europeana introduced the Musical Instruments Museum Online Project (MIMO), which can be considered a significant attempt to update the "-phone" system to include instruments used in electronic music. This project lists notable electronic instruments such as the Mellotron and some digital/MIDI-capable samplers. A meaningful path for digital organology that involves generative instruments would be to pursue an approach that does not involve revisions on and responses to an ultimately incompatible system such as the Hornbostel and Sachs approach. These top-down systems are geared towards instrument curation and are far too broad to effectively reflect ideas about a player's experience or the social context in which lutherie took place. In terms of their compatibility with generative electronic music, such systems fail to address how through practice, the construction of digital instruments can be quite varied, malleable-- that they do not always require the use of fixed components to be viable in music creation settings. An organology for generative electronic instruments should acknowledge their fluctuating construction, and their relationship to emerging digital cultures.

Recent work in musicology and music theory has acknowledged the problematic nature of using relying of this status quo of musical instrument classification. In his book "Music at Hand," theorist Jonathan De Souza argues that the Hornbostel-Sachs system reveals the 19th century European origins of organology –that an attempt to form a universally applicable scientifically-based model was outgrowth of the prestige that acoustical research carried at the time. (De

Souza 2017, 34) In his book “The African Imagination in Music,” musicologist Kofi Agawu argues that the system, again due to its intended use for curation purposes, fails to address the manner in which Africans conceptualize and experience their instruments. He refers to Hornbostel-Sachs as a colonial classification system that flattens the unique identity of African instruments. (Agawu 2016, 81) In working towards a system for classifying instruments used in generative electronic music, approaches that focus on musical behavoiur, social context and provide a broad view of the performer provide a good theoretical basis.

Certain non-western approaches, especially those based on oral and not written traditions show new possibilities outside of the stream of variations on the Hornbostel-Sachs system. In her book “On Concepts and Classifications of Musical Instruments,” Australian ethnomusicologist Margaret Kartomi discusses, for example, West African approaches based on the myth and mode of transmission to the human realm, or religious and historical factors such as use in ritual ceremony. (Kartomi 1990, 241) The example below focuses on musical function and spatial elements (performing position) instead of materials. The presence of established systems based on oral traditions bring forth questions about digital technologies, in which

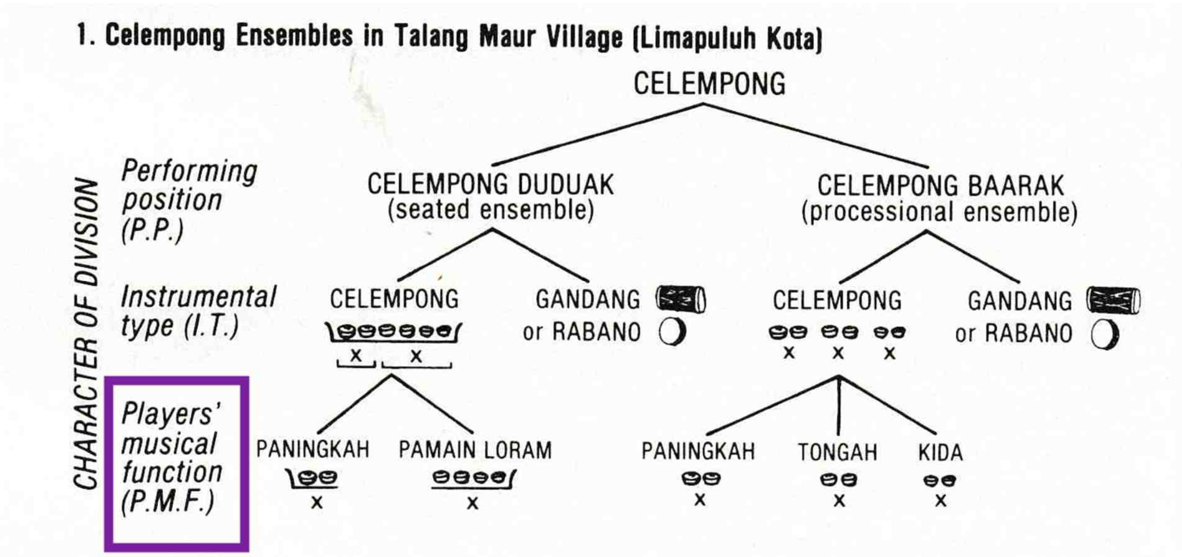

Figure 10: Excerpt of classification system used in Minangkabau music of West Sumatra (Kartomi 1990, 230)

functions and relationships between technologies, users and observers might be a more pertinent than materiality. Digital storytelling, like the development of classification systems for musical instruments, or even digital lutherie itself, works as an approach to capturing cultural activities and emerging traditions. Efforts to link software and oraily do exist in arts-based reserach. For example, The Centre for Oral History and Digital Storytelling (COHDS) at Concordia University developed “Stories Matter,” a free and open-source software for oral historians that encourages the use of digital media and encourages a shift away from the use of transcription. (Zembrzycki 2011, 101) Historian Stacey Zembrzycki used the software for documentation of the Ukranian community in Sudbury, Ontario. Zembrzycki writes that working through a database of digital media such as audio and video recordings allowed her to “…appreciate the humanism and collaborative nature of the interview space.” (Zembrzycki 2011, 101) In this sense, digitality and the behaviours that stem from digital media brings about a new approach to writing about culture.

The approach used Herbert Heyde's 1975 book "Fundamentals of the Natural System of Musical Instruments" presents a compelling alternative to Hornbostel-Sachs in using an approach to organology based on cybernetics. The way in which player and instrument are blended into the idea of what Heyde adapts to the idea of a "control circuit" shows that he thought about instruments as an aggregation of both components and behaviours. For example,

Table 2.2 Instrumental elements from Heyde (1975)

Label	German term	English term	Examples
A	*Anreger*	Activator	Muscles, lungs, bellows
V	*Vermittler*	Mediator	Violin bow, guitar pick, piano keys
W	*Wandler*	Transducer	Strings, membranes, reeds
ZW	*Zwischenwandler*	Intermediate transducer	Electric guitar pickup
M	*Modulator*	Modulator	Distortion pedal, electronic organ tone filter
Ampl	*Amplifikator*	Amplifier	Electric guitar amp, loudspeaker
R	*Resonator*	Resonator	Violin body, piano soundboard
K	*Kopulator*	Coupler	Flute tube
[circle]	*Kanal*	Channel	Violin bridge, flutist's throat
St	*Steuerelement*	Controller	Fingers, keys, switches

Figure 11. Excerpt from Hyde's "Fundamentals of the Natural System of Musical Instruments" (De Souza 2017, 34)

the "Kanal" component in the table below includes both the flautist's throat and a violin bridge. The possibility for substitution that exists within Heyde's system makes it a good jumping off point for thinking about an organology for generative musical instruments, which often migrate to inhabit different technologies, or expand and adapt to include new devices while still maintaining the same instrumental status. In his research on the networked laptop orchestra, de Souza argues that Heyde's approach is useful for thinking about an ensemble of connected computer performers as an orchestra based on the "interchangeability of anthropomorphic and technomorphic elements cybernetics posits." (De Souza 2018, 162) In the laptop orchestra, cybernetic performers can be chained together from combinations of humans, speakers and audio devices. The question now becomes: how to develop a compatible system for classifying generative musical instruments that builds on existing organological approaches that prioritize behaviour, function and position digital lutherie as hybridized form of sonic writing that combines lived experience, genre possibilities and alternative ways of documenting ideas about music (e.g. coding)?

The image below shows a portion of the user interface for "The Gestrument," an instrument played using mobile devices that was initially made in 2007 by Swedish composer Jesper Nordin as a desktop software for Max/MSP, a graphical programming environment for audio and other media projects. As a mobile device app, the instrument relies on various tapping and swiping gestures. The instrument is generative in nature as the performer's actions amount to a shaping of automated musical patterns. What functions as an instrument to be played is really the interaction with automated systems when you press or swipe on the interface –not so much the aspects of timbre, range or the physical materials suggested by the bank of presets such as "Klezmer" or "Minimalistic Sax." In a 2018 presentation at the Royal College of Music in Stockholm, Nordin demonstrates the instrument by hacking a MIDI rendition of Beethoven's "Fur Elise" in which touch and gesture on a tablet affect aspects of register, tempo and *chromaticizing* the harmony by altering chords to make them more dissonant. The instrument analyzes and then allows users to modify MIDI data, extract and impose patterns using the interface. Nordin describes his motivation for the Gestrument was "…being able to define rules, play within them and to change the rules while I was playing." (Nordin 2018) Figure 13 shows an approach to classifying the Gestrument by collecting nodes in a table. In terms of mode of transmission, the standard version of the app relies on a mobile device, but a node is also provided as the instrument can envelop other technologies to become an assemblage. For example, in March of 2021, the Basel Sinfonetta premiered a work in which the conductor simultaneously directs the orchestra and improvises using the Gestrument. Here, instead of the intimate experience of swiping and tapping on a mobile phone or tablet, the instrument is augmented using Microsoft Kinect, a motion controller commonly used with the Xbox gaming console. While Nordin claims that the gestrument is genre agnostic, (Nordin 2018) the use of digital technologies to generate sound cannot occupy virtually any genre as some kinds of music depend on instruments that consist of a very particular set of materials (e.g. you cannot perform Gregorian chant with this instrument as it cannot deliver text; the technologies to simulate voices in such a fashion do not exist), but we can spread nodes across a broad set of genres used in generative and/or digital music practice to describe the Gestrument's wide reach. While there are many possible uses for such an instrument, its much of its recent use seems focused concert performances that extend from Nordin's activity as a composer. The use of pattern extraction via MIDI analysis of pitch, velocity, etc. that are affected by physical gestures places two nodes in the interactivity section of this model.

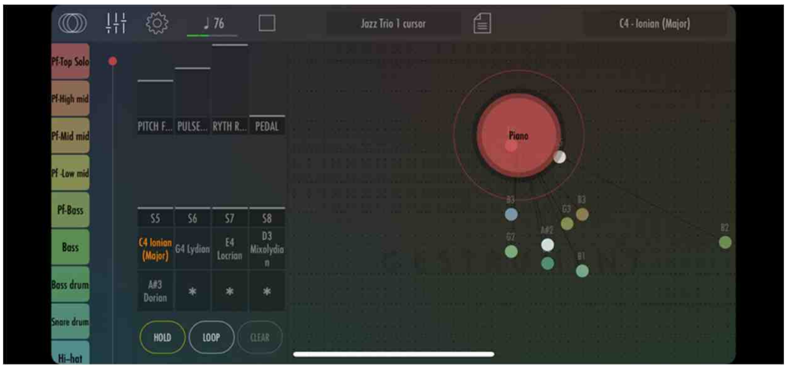

Figure 12: Excerpt of user interface from Gestrument (Gestrument AB 2018)

My classification model adapts Kartomi's presentation of a West African system based on myth. It's chosen as a jumping off point because of the emphasis on transmission, making and ownership by humans and non-humans. Ideas from cybernetics such as the "assemblage" and "additive" categories are added as a link to ideas from Heyde's cybernetic approach such as substitution between human and non-human agents as part of the same "control circuit." Circular causality, a defining feature of what is referred to as "second order cybernetics" (a study of control systems and communication in which the role of the observer is also acknowledged) is also incorporated in this model as a way of accounting for instruments that are played through different levels of participation, both active and passive. Cybernetician Ranulph Glanville describes the levels of circularity in second-order systems as including " …the circularity of the system under consideration, that is, the observed system. And secondly, there is the circularity of the act of observing, that is, of the observing the observed system." (Glanville 2014, 191 For example, circularity is represented in the "analysis/data input" and "visual" categories of the "Interactivity" area of the model, in which feedback can exist between the initial analysis and mappings of data to sonic parameters and is then subsequently controlled as users/audience perceive said mappings.

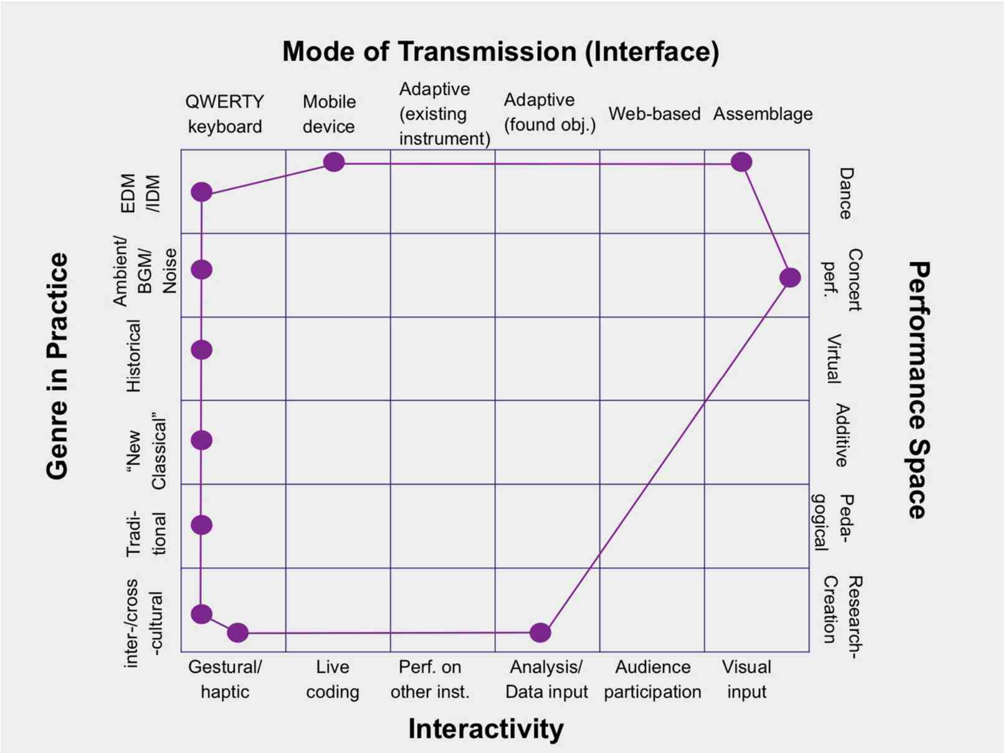

Figure 13. A classification model for generative musical instruments – applied to the "Gestrument"

The "Bloom" app by Brian Eno and Peter Chilvers serves as a good example of generative electronic instruments adopt circularity. As an instrument, the mobile version of "Bloom" uses both gestural and visual input (I use this category to describe both the detection of visual camera input, and the use of abstract graphics that trigger actions). The performance space is additive. This means that multiple performance spaces can be occupied at the same time. An example of this has been in the use of "Bloom" for performance in an installation environment. In 2018, Eno and Chilvers partnered with Microsoft to create a mixed reality installation in Amsterdam's Transformatorhuis arts space that allowed for simultaneous group interactions using the same kind of generative audio-visual setup but with larger devices such as Microsoft's HoloLens smart glasses. (Ray 2018, para.2) In terms of genre possibilities, the app falls in line with Eno's particular brand of ambient music. The venue, or how the performance space can function as both the user interface and the expanded realization of the app through the physical installation space is where feedback is established – here between the user and the app, along with observed interactions of the app being used by installation users in the physical venue.

Figure 14: Basel Sinfonetta performance featuring the Gestrument

This approach to musical instrument classification is not only a matter of mere organization. It is classification. It is a tool for understanding positionalities that are revealed from interactions in generative electronic music. Just as Kartomi's presentation of an approach from West African musical cultures show how instruments can document how relationship between human and nonhuman entities are accessed through spirituality, a classification approach for generative electronic instruments can reveal power dynamics between human and nonhuman entities that are accessed through algorithms. The manner in which George E. Lewis' "Voyager" software engages in dialogue with its co-performer(s) also reveals something about agency in computer music improvisation. In his article "Interacting with latter- day musical Automata", Lewis comments on the use of *non-motivic* approach to form, instead describing a "state-based model" that uses a "global aggregation" of sonic information instead of a linear transformation of gesture, which he considers culturally situated in a Eurocentric mode of thinking about improvisation. (Lewis 1999, 105) Lewis also considers his development of a non-hierarchical system as a response to the manner in which narratives about mastery of control have shaped a computer music practice that is highly influenced by Eurocentric concert music perspectives, especially with its emphasis on the use of "controllers" – e.g. devices to control various sound-making parameters. He instead considers the

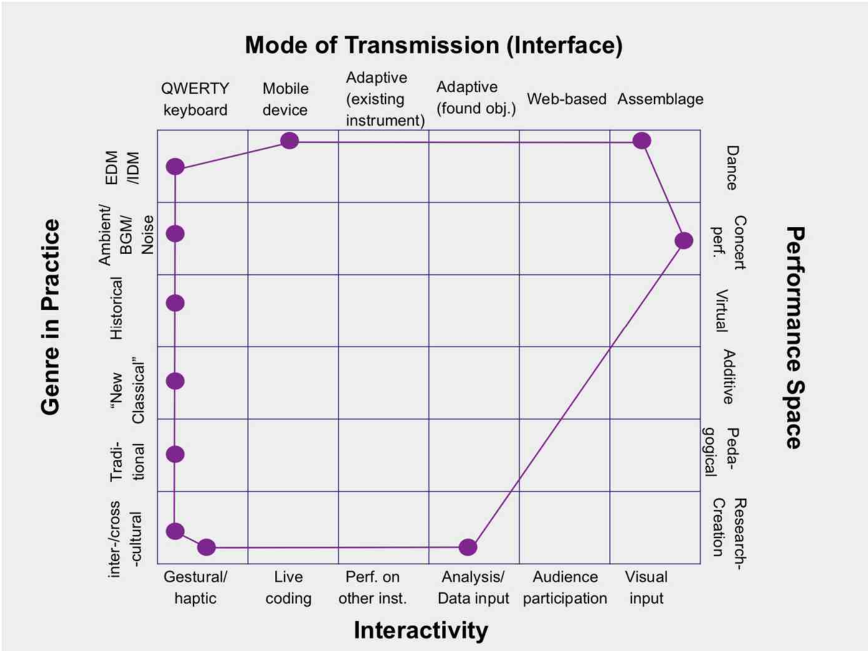

Figure 15. A classification model for generative musical instruments – applied to the "Gestrument"

possibility of "non-controllers, involvers or enablers." (Lewis 1999, 108) One of the benefits of this model for classification is that it reveals dependencies between certain aspects of an instrument. Here, the circularity between performance and analysis as a basis for interactivity in "Voyager" is foregrounded to demonstrate Lewis' thoughts on what kind of data should fuel computer music improvisation. The classification system is an analytical tool that helps promote certain ways of thinking about music. Here, my model helps those unfamiliar with generative electronic instruments understand the fluid nature between venue, the importance of assembly and substitution in lutherie and use, and for the relationship between observation and performance. It highlights the way in which live analysis is an important component in playing many such instruments – or, in the words of cyberneticist George Bateson, that "no data are truly 'raw,' and every record has been somehow subject to editing and transformation by man or his instruments." (Bateson, 1972, p. xviii)

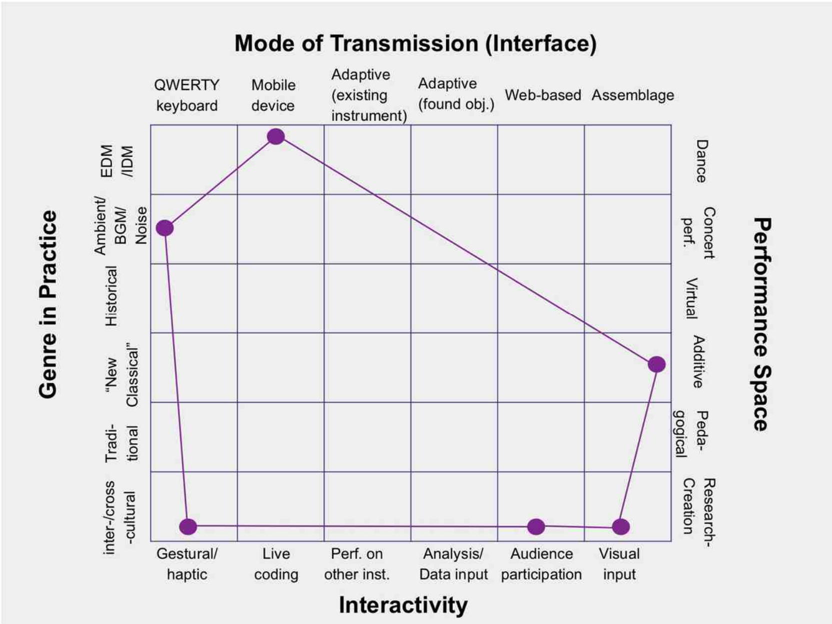

Figure 16. A classification model for generative musical instruments – applied to "Bloom"

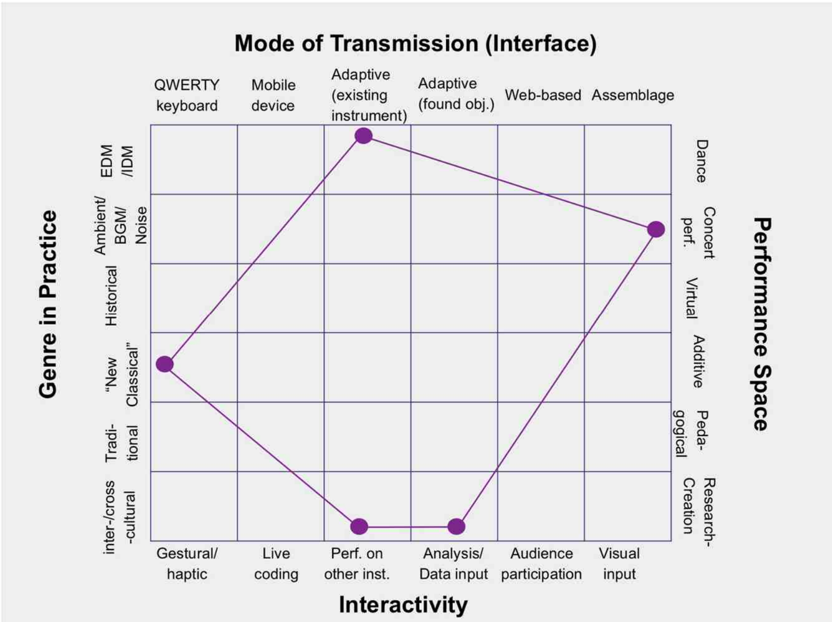

Figure 17. A classification model for generative musical instruments – applied to "Voyager"

1.4 The Algorithmic Gamelan

Considering the substantial influence that Indonesian gamelan music has had on composers of the 20th and 21st century, the manner in which digital instrument designers have reinterpreted gamelan music has provided a worthwhile area for exploring issues of cultural heritage, identity and borrowing. The origin of the gamelan's influence beyond Southeast Asia can be traced to its presentation at the 1889 World Exposition in Paris. The way in which this event affected composers such as Claude Debussy and Erik Satie that contributed to the development of musical modernism in European classical music and a shift away from the hegemony of major-minor tonality (even if the shift was based on appropriation rather than understanding). Author and electronic musician David Toop's "Ocean of Sound" refers to the Paris Exhibition as a major paradigm shift, in which "cultural confrontations became a focal point of musical expression." (Toop 1996, 2) Electronic music works such as the synthesizer arrangements of Debussy's music in Japanese electronic music pioneer Isao Tomita's 1974 album "Snowflakes are Dancing" used an electronic instrument, the Moog III synthesizer, to reorchestrate and in some cases add material where Tomita felt the composer's choices were ineffective. (Brown 2012, 75) Work such as Tomita's contribute to a trend consisting of appropriations and responses that stem from the experience of early modern era French composers at the 1889 exhibition. Recently, the gamelan's influence on electronic music has branched into the domain of digital lutherie and generative sound work. In particular, computer musicians have created apps and code-based instruments to produce instruments that not only draw on the timbres but also the behaviours of the gamelan ensemble.

The digitization of gamelan music leads to important considerations about whether computer technologies and instruments that hold significant cultural weight can in fact work symbiotically with each other. Indian cultural theorist Homi Kharshedji Bhabha writes that hybrids have the potential to create an "intederminate third space" that can be used to subvert political and cultural hegemonies. (Steele 2015, 190) The idea of music technology facilitating the creation of such a third space has been practiced by electroacoustic composers interested in inter/cross-cultural work. For example, in describing his piece "Twelve Landscape Views: III. Guqin, Saxophone, Electronics," Jeff Roberts states:

"In the context of working in an intercultural electroacoustic context in with timbre, while technology and the drive to innovate is a cultural feature of the West, the application of technology can be applied to a context where the sonic world and connected meanings of Chinese or Tuvan culture take the lead in shaping the way in which technology is used to enhance and extend timbre and meaning from these cultural perspectives." (Roberts 2014)
To avoid the imposition of technology in a way that highlights notions of cultural difference, it is worth asking: who are these new digital gamelans really for? Are those working with music technologies from outside of Indonesia guided by a different set of principles? Music technologies have played a role in problematic forms of cultural appropriation in which innovation through fusion becomes a kind of double-edged sword. In his chapter from the 2019 book "Rethinking Reich," music theorist Martin Scherzinger has investigated Reich's notable use of *phase shifting* techniques drawn from electronic music. The author refutes the composer's claim that his incorporation of elements from African music was a confirmation of the stylistic direction that he was pursuing through the use of loops growing in and out of phase, instead arguing that Reich's electronic work was drawn out of rhythmic and textural aspects of African drumming that the composer absorbed during his period of study in Ghana. (Scherzinger 2019, 261) The need to investigate such power dynamics carries forward into recent computer music. For many musicians who work with algorithms, gamelan music becomes attractive in its compatibility with programming practice (e.g. the propensity for nesting of rhythmic objects such as patterns, and the use of intricate formal structures that offer an alternative to the broad harmonically goal-oriented models that dominate European classical music).

A good example of this hybridization of gamelan and musical programming to form generative electronic instruments is the Virtual Gamelan Graz (aka VGG) project, which started in 2012 at the Institute of Ethnomusicology of the University of Music and Performing Arts in Graz. The project was designed to computationally model timbre of instruments and performance practice for unveiling tacit information about Central Javanese gamelan music is not easily expressed through established forms of musical analysis. (Grupe 2008, 1) Additionally, the project was concerned with producing materials that could facilitate new musical works that involved blending gamelan with other technologies such as live processing with effects. (Grupe 2008, 3) Efforts to make software instruments that were compatible with Windows represents a reaching out towards technologists and artists beyond Europe and North America where computer music work tends to demonstrate a strong preference for the Mac OS. The project also reaches out for authenticity in the way that it tries to implement the *Kepatihan*-style cipher music notation that is commonly used by Javanese gamelan music within the coding language used to make the VGG software. Project members Rainer Schütz and Julian Rohrhuber write that although this transference to code-based notation "…required making some compromises, simple patterns will still look quite familiar to those familiar with Kepatihan, and it should not be too difficult to get accustomed to the special features of the VGG derivative." (Schütz and Rohrhuber 2008, 133)

While this project does not link to cultural factors such as the relationship between Gamelan and ritual and community events in Indonesia (e.g. weddings, shadow theatre), it does work as a valuable research-creation effort in the development of code-based musical practices that strive for a more empathetic route than the exoticism of Debussy. The VGG's choice of the SuperCollider programming language is interesting in that it contains a robust pattern-based system for controlling musical time, where other comparable tools (e.g. ChucK, RTcmix, CSound) rely more on timing control structures drawn from general purpose programming languages such as C/C++. This sense of compatibility is also evident in naming choices used in the code. They do seem to make an earnest attempt to view code as a notation, rather than an abstraction, for specific musical practices stemming from gamelan music. 18 shows this aspect of VGG's hybridization of code and gamelan in which Boolean (i.e. testing if/else) logic conditions are stated according to actual terms from gamelan practice. For example, satisfying a condition can lead to mcDoSuwuk (suwuk being an object in the structure of an improvisation that triggers an ending). (Schütz and Rohrhuber 2008, 148) As a predominantly text-based set of objects for virtual gamelan performance, the generative musical instrument becomes the typed commands themselves. Schütz and Rohrhuber state that their SuperCollider-based instruments are "…not just the technical means to finally implement an already existing model, but also a part of an experimental and iterative process. It extends the idea of the integration of knowledge and computation by the concept of interactive writing." (Schütz and Rohrhuber 2008, 143) The VGG package shares similarities with previously discussed traits of generative musical instruments. They are databased in that they store and provide access to coded behaviours, and through the playing based on launching and interfering with patterns, they are interactive through the use of automation.

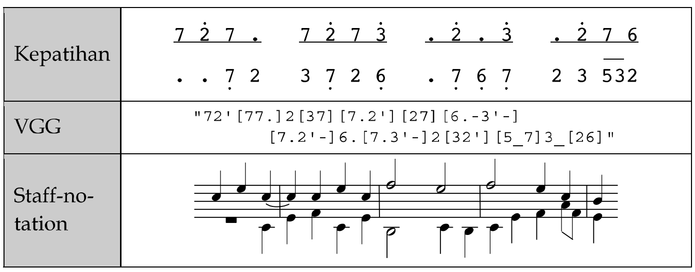

Figure 18. Approximation of Kepatihan notation using the SuperCollider programming language

```
event-stream.tagable.tag = (mcGoToNgelik: true);
event-stream.tagable.tag = (mcDoSuwuk: true);
event-stream.tagable.tag = (mcGoToNgelik: false);
event-stream.tagable.tag = (mcDoSuwuk: false);
```

Figure 19. Triggering streams of events using terms specific to gamelan practice (Schütz and Rohrhuber 2008, 148)

Code-based instrument projects such as those in the VGG are valuable in that they are comprised of highly sharable and potentially free and open-source (at present only bits and pieces of the VGG material have been made available to the public). This helps address the question of purpose (who are these efforts really for?). A group of European ethnomusicologists and scholars might not be able to make the same strides towards digital gamelan as a component of cultural preservation or use creative technologies to imagine how cultural heritage evolves into the future, but they can at least present their efforts for the benefit of any interested parties, rather than jumping towards commodification (as is so common in the world of audio plugins and MIDI tools) or claiming ownership over a cultural object by encapsulating it within an original musical score. The representation of the instrument through a series of text files echoes what some media scholars have written about the relationship between digital formats and resistance. In his book “MP3: The Meaning of a Format,” Jonathan Sterne describes how users of digital formats circumvent different kinds of uses that are observed in digital rights management and exercises power over manufacturers. (Sterne 2012, 199) An .scd (SuperCollider language) file has a similar potential, especially since object-oriented programming allows for exchange of similar logic based on modifying syntax to fit a user’s desired language.

Indonesian efforts to interact with gamelan through computer music algorithms seem to be guided by concerns of accuracy and the preservation of cultural heritage, rather than hybridization and the lure of new research and compositional possibilities that might emerge from digital versions of these instruments. The first recorded experiments with computer representations of gamelan music were presented in 1977, by scholars at Gadjah Mada University in Indonesia. This was a research was based on creating algorithms for generating *balungan* (a kind of melodic skeleton for a piece) sequences. The computer scientist Khafiizh Hastuti has been involved with some of the more visible recent work that involves the production of research and technologies using algorithmic play with digital gamelan sounds. Her contributions to “the algorithmic gamelan” shows how a different set of motivations from Western efforts such as the Virtual Gamelan Graz projects. In a monograph written by the Gamelan Research Project at Dian Nuswantoro university, a lab led by Hastuti, the authors discuss the importance of Indonesian people being the main provided of online information about gamelan. They refer to the problem of Western Internet technology dominating the ownership and control of available information about gamelan, which then leads to overrepresentation of figures who hybridized gamelan with musical modernism such as the American composers John Cage and Lou Harrison, instead of Javanese artists. (Hastuti et. al 2019, 243) To promote Indonesian ways of understanding of this tradition, the group made meaningful strides towards using software as a tool for such knowledge dissemination.

The Gamelan Research Project has presented apps that serve educational purposes in which users are guided to affect algorithmic processes that link to digitally reproduced gamelan sounds. In 2013, they presented findings on their “Gamelan Composer,” which uses techniques from machine intelligence such as data pruning[1] to present choices for melody notes to the user that are weighed as more or less authentic in traditional Javanese gamelan music.[2] What's notable about the work coming from technologists such as Hastuti vs. that of VGG is the way interactivity is prioritized over the idea of presenting a robust database of characteristics and behaviours. The scope of an app such as "Gamelan Composer" may not give access to characteristics beyond melody generation, but the presence of a guiding mechanism points to the idea that the instrument is not for unveiling some kind of tacit/hidden magic about gamelan music, but to train users according to the authors' perspective on this kind as a group of technologists who live in close proximity to gamelan tradition. Hastuti and her collaborators refer to their apps as opportunities for knowledge transfer to the Indonesian community and refer to accessibility issues such as the expense, space and access to experienced musicians required to teach gamelan music. (Hastuti et. al 2019, 240) This idea about the manner in which accessibility issues are resolved by digital instruments is echoed in Magnusson's statement that "…young people often enter the world of music through digital technologies (e.g., apps and games)," suggesting that the digital systems of some sort can become natural instruments for contemporary musical expression.

A good representation of the Gamelan Research Project's "digital gamelan instrument as an interactive learning app" can be seen in their 2020 creation: "Smart Gamelan: Demung Laras Pelog." This app becomes a generative instrument by having the user select performance settings, play alongside an automated virtual gamelan performer, and continuously receive feedback and suggestions based on input. There is a circularity between player deciding on a framework (e.g. pitch, rhythmic parameters) and interaction with the virtual performer instructor based on these decisions. Hastuti's monograph describes the "Learn Mode" of the app as simultaneously evaluating the user's performance, accuracy of choices against a target within a given timeline. The databased, automated, interactive and even hypertextual nature (based on the non-linear approach to accessing information about gamelan through libraries of different *barang, lima* and *nem* musical scales) positions this app as a full-fledged generative electronic instrument. It's reliance on player analysis shares similarities with Lewis' "Voyager" system. Depending on the manner in which the user syncs with virtual instructor's automated play, positionalities about authentic gamelan performance can be revealed.

[1] Data pruning is a technique used to ascertain non-critical/redundant data for develop training sets for machine learning by testing against sets of rules

Figure 20. Learn mode for Smart Gamelan app

1.5 Conclusion

Whether through the western analysis and hybridization-driven approach of groups such as the Virtual Gamelan Graz project, or through Indonesian efforts by technologists like the Gamelan Research Project at Dian Nuswantoro university, we can view the creation of digital gamelans shaped by algorithmic interactivity as an exercise in the power dynamics that inevitably carry into generative lutherie, and extending to instrument building of many kinds. Either through creation of new and user-friendly technological resources for understanding Indonesian perspectives on gamelan music, or through promotion of creative works that unveil these perspectives, it is obvious that a power imbalance exists in those Western representations of “the algorithmic gamelan” are far more visible in prominent international research and creation resources. Composer and mathematician Gareth Loy in states that the analysis of algorithms “…can be shown to demonstrate not merely clever means to ends, but, more important, it can reveal the value systems -- the true aims --- of individuals and cultures: because what is formalized into algorithms is always the essence of what is felt to be central to an enterprise…” (Loy and Todd 1991, 293) David Cope, a pioneer of artificial intelligence in music, points to the value of pursuing non-Western perspectives in computer music projects. Cope describes collaborations in Bali and on Indigenous communities such as reservations in the United States, saying that in his experience “… curiosity and respect for all things, living and nonliving, far outweighs any antagonism towers machine creativity that one finds so often with Western sensibilities.” (Cope 2000, 261) I would not consider Cope’s experiments with style replication and fusion (e.g. his “Mozart in Bali” composition) as fully problematic, I do feel that it highlights the disparity in representation of certain perspectives. There is now a greater need to acknowledge and/or cultivate intersections between algorithms and culture that focus more on lived experience with heritage, and to consider how instrumentality helps establish these relationships.

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N-제곱 함수를 기반으로 하는 비선형 전달함수 시스템의 출력 신호 해석

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본 연구에서는 비선형 함수를 전달함수로 가지는 시스템에 입력한 임의의 오디오 신호의 출력 결과를 해석하는 방법에 대해 알아볼 것이다. 대부분의 비선형 함수들은 테일러 전개, 그 중에서도 매클로린 급수를 이용하면 N-제곱 함수들의 선형적 결합의 형태로 풀어서 설명될 수 있다. 이 경우, N-제곱 함수를 전달함수로 가지는 시스템의 입출력 관계를 설명할 수 있다면 꽤 복잡한 비선형 함수라 해도 이를 전달함수로 가지는 임의의 시스템의 출력 신호를 설명할 수 있을 것이다. 먼저 N-제곱 함수를 전달함수로 가지는 시스템의 특성에 대해 논한 후, 출력 신호 예측의 사례를 제시하고 나아가 비선형 전달함수를 가지는 시스템을 해석하는 방법을 매클로린 급수의 도움을 받아 알아본 뒤, 이 역시 사례를 제시하고 제시된 전달함수를 바탕으로 파형성형법으로 새로운 소리를 만들어 볼 것이다.

주제어: 비선형 변환, 매클로린 급수, 파형성형, 전달함수, 신호처리, 시스템, 합성함수

수많은 소리 합성(Sound Synthesis)법 중에서도 흔히 "**Waveshaping**"이라 불리는 "**파형성형**"이란, 어떤 입력 신호를 임의의 시스템에 입력한 후 **전달함수**(Transfer Function)를 통해 입력 신호를 변환하여 출력 신호에서 입력과는 다른 결과를 얻어내는 방법이다. 입력 신호의 세로축의 값은(표본값이라는 개념으로 이해할 수도 있을 것이다) 통상적으로 x, y 양 축 상에서 ±1 의 범위에 걸쳐 형성된 전달함수 테이블에서의 일종의 "x 축 상의 인덱스"가 되어 전달함수의 함숫값을 읽어낸 뒤 보간(interpolation) 작업을 적절히 진행하면, 그것이 시스템의 출력 신호가 된다. 이 과정은 **합성함수**(composite function)에서의 연산과정과 같은 맥락에서 이해될 수 있다.

파형성형의 장점은 효율적으로 많은 부분음들을 생성해낼 수 있다는 점도 있겠지만(따라서, 파형성형을 "왜곡 합성(Distortion Synth)법"이라는 범주 안에 넣는 경우도 적지 않다), 그 결과로 얻은 변형된 신호의 배음 구조를 정확히 예측하는 것이 가능하다는 것이다. 특히 <u>N-제곱 함수가 전달함수일 때</u>에는 부분음(Partial)들 중 최고음이 어느 지점에 존재하는지 미리 알 수 있으며, 이로 인해 주파수 변조(FM)와는 달리 대역 제한적(Band-Limited)인 소리합성법이라고 생각할 수 있다.

이처럼 많은 추가적 부분음들을 효율적으로 얻어내기 위해서는 파형성형을 위한 시스템의 전달함수는 당연하게도 비선형(Non-Linear) 함수가 되어야 유리하다. 그렇지만 비선형 함수가 전달함수일 때, 출력 신호는 직관적으로 예측하기 쉽지 않다. 그러나 이 말이 곧 출력 신호의 주파수 성분들을 예측하는 작업이 불가능하다는 말은 절대 아니다. 본 연구에서는 간단한 형태의 비선형 전달함수를 가지는 시스템에 다양한 형태의 입력 신호를 부여한 후 나오는 출력 신호를 시간 영역과 주파수 영역에서 관찰해보고, 이 과정에서 얻은 단서를 바탕으로 점점 더 복잡한 비선형 시스템을 통해 얻을 수 있는 파형성형된 신호의 특성을 비교적 효율적으로 알아내는 법을 알아본다.

"N-제곱" 형태의 전달함수를 가지는 시스템

1) 입력신호가 단순 정현파일 경우

흔히 알려져 있듯이 N-제곱 형태의 전달함수에 진폭이 1 인 단위 정현파를 입력하는 경우, 최고차 배음성분의 위치를 비롯한 출력신호의 성분을 예측하는 방법은 그리 어렵지 않

다. Charles Dodge는 그의 책[1]에서 이항정리와 파스칼의 삼각형을 이용한 N-제곱 전달함수 시스템의 출력 신호를 구성하는 부분음 성분들의 강도값을 계산하기 위한 도표를 제시하였다. 해당 도표와 같은 맥락의 내용이긴 하나, 조금 더 수학적인 표현을 통하여 N-제곱 전달함수 시스템의 출력 신호 계산법을 아래에 나타내 보고자 한다. 잘 알려져 있듯, 자연수 N이 홀수일 때와 짝수일 때의 결과는 다른 양상을 보인다. 아래에 나타낸 식 1 속의 두 수식을 보자.

(1)

$$\cos^{2n}x = \left(\frac{1}{2}\right)^{2n} \cdot {}_{2n}C_n + \left(\frac{1}{2}\right)^{2n-1}\sum_{k=0}^{n-1} {}_{2n}C_k \cdot \cos2(n-k)x$$

(2)

$$\cos^{2n+1}x = \left(\frac{1}{4}\right)^{n} \cdot \sum_{k=0}^{n} {}_{2n+1}C_k \cdot \cos(2n+1-2k)x$$

식 1. 본문의 문단 편집 화면.

식 1 속 *(1)*의 경우 N 이 짝수, 즉 진폭이 1 인 단위 정현파를 짝수 번 제곱한 경우의 결과를 말해주고 있는 식이다. 이산 합(Sigma)의 항 앞에 DC 성분을 나타내는 항이 있음을 알 수 있고, 결과적으로 $\cos x$성분을 짝수 번 제곱하면 DC 성분과($\cos 2x$부터 $\cos 2nx$까지의) n 개의 부분음들이 생겨난다. 마찬가지로 식 1 속 *(2)*를 참고하여 단위 정현파를 홀수 번 제곱하면 DC 성분 없이($\cos x$부터 $\cos (2n+1)x$ 까지) 총 n+1 개의 부분음들이 생겨난다. 만약 시스템에 입력되는 정현파의 진폭이 1 이 아니라 임의의 값인 a 라면, a^{2n} 혹은 a^{2n-1}을 식 1 속의 각 항에다 곱해주면 된다.

만약, N-제곱 함수의 선형적 조합으로 표현될 수 있는 전달함수를 쓴다면, 이 역시 상기한 수식으로 각 N-제곱 전달함수에서의 결과를 계산한 이후 결과들을 합하면 된다. 예를 들어, 입력신호가 단위 정현파이고 어떤 시스템의 전달함수가 $f(x)=x+x^2+x^3+x^4+x^5$ 인 경우, 각 부분음 성분들은 다음과 같이 계산된다. 우선 x^2, x^4 는 *(1)*을, 그리고 x, x^3, x^5 는 *(2)*를 이용해야 한다.

[1] Computer Music: Synthesis, Composition, and Performance(1997)

(1)

$(n=1)$

$$\cos^2 x = \left(\frac{1}{2}\right)^2 \cdot {}_2C_1 + \left(\frac{1}{2}\right)^1 \cdot \sum_{k=0}^{0} {}_2C_k \cdot \cos2(1-k)$$

$$= \frac{1}{2}(\cos2x+1)$$

$(n=2)$

$$\cos^4 x = \left(\frac{1}{2}\right)^2 \cdot {}_4C_2 + \left(\frac{1}{2}\right)^3 \cdot \sum_{k=0}^{1} {}_4C_k \cdot \cos2(2-k)$$

$$= \frac{1}{8}(4\cos2x+\cos4x+3)$$

$(n=0)$

$$\cos x = \left(\frac{1}{4}\right)^0 \cdot \sum_{k=0}^{0} {}_1C_k \cdot \cos(1-2k)x$$

$$= \cos x$$

$(n=1)$

$$\cos^3 x = \left(\frac{1}{4}\right)^1 \cdot \sum_{k=0}^{1} {}_3C_k \cdot \cos(3-2k)x$$

$$= \frac{1}{4}(3\cos x+\cos3x)$$

$(n=2)$

$$\cos^5 x = \left(\frac{1}{4}\right)^2 \cdot \sum_{k=0}^{2} {}_5C_k \cdot \cos(5-2k)x$$

$$= \frac{1}{16}(10\cos x+5\cos3x+\cos5x)$$

식 2. 식 1을 이용하여 계산한 코사인함수 거듭제곱의 결과들.

이 결과들을 모두 합하면 $f(x)=x+x^2+x^3+x^4+x^5$를 전달함수로 갖는 시스템을 통과한 정현파가 아래와 같이 어떤 주파수 성분들(부분음)을 어떤 강도로 가지는지 모두 알 수 있다. 아래에 그 결과가 나타나 있다. 그리고 이를 각 부분음마다 정리하여 그 강도값을 산출한 결과도 아래에 함께 보인다.

$$\tfrac{1}{2}(\cos2x+1)+\tfrac{1}{8}(4\cos2x+\cos4x+3)+\cos x$$
$$+\tfrac{1}{4}(3\cos x+\cos3x)+\tfrac{1}{16}(10\cos x+5\cos3x+\cos5x)$$

$$\mathrm{DC}: \tfrac{1}{2}+\tfrac{3}{8}=\tfrac{7}{8}$$

$$\cos x: \cos x+\tfrac{3}{4}\cos x+\tfrac{10}{16}\cos x=\tfrac{38}{16}\cos x$$

$$cos2x : \frac{1}{2}cos2x+\frac{4}{8}cos2x=cos2x$$

$$cos3x : \frac{1}{4}cos3x+\frac{5}{16}cos3x=\frac{9}{16}cos3x$$

$$cos4x : \frac{1}{8}cos4x$$

$$cos5x : \frac{1}{16}cos5x$$

식 3. 전달함수가 $f(x)=x+x^2+x^3+x^4+x^5$인 시스템을 정현파가 통과하여 얻게 되는 출력 신호의 주파수 성분 계산 결과.

만약 입력 신호인 정현파의 진폭이 1이 아니라면, 전술한 대로 진폭을 나타내는 계수 a의 거듭제곱수를 식 2의 각 항에 곱해서 계산을 진행해야 한다. 이 a라는 값은 "**왜곡 지수**(distortion index)"라는 용어로 잘 알려져 있다. 위 계산 결과를 다시 이용하여 왜곡 지수에 따른 각 부분음 성분들의 강도 변화 양상을 수식의 형태로 관찰하면 아래와 같다.

$$\frac{1}{2}(cos2x+1)\cdot a^2$$

$$+\frac{1}{8}(4cos2x+cos4x+3)\cdot a^4$$

$$+cos\,x\cdot a$$

$$+\frac{1}{4}(3cosx+cos3x)\cdot a^3$$

$$+\frac{1}{16}(10cosx+5cos3x+cos5x)\cdot a^5$$

이를 계산하면,

$$\frac{1}{2}(cos2x+1)a^2+\frac{1}{8}(4cos2x+cos4x+3)\cdot a^4+cos\,x\cdot a$$

$$+\frac{1}{4}(3cosx+cos3x)\cdot a^3+\frac{1}{16}(10cosx+5cos3x+cos5x)\cdot a^5$$

$$DC : \frac{a^2}{2}+\frac{3}{8}a^4$$

$$cosx : a+\frac{3}{4}a^3+\frac{10}{16}a^5$$

$$cos2x : \frac{a^2}{2}+\frac{a^2}{2}$$

$$cos3x : \frac{a^3}{4}+\frac{5}{16}a^5$$

$$cos4x : \frac{1}{8}a^4$$

$$cos5x : \frac{1}{16}a^5$$

식 4. 전달함수가 $f(x)=x+x^2+x^3+x^4+x^5$인 시스템을 진폭이 a인 정현파가 통과하여 얻게 되는 출력 신호에서의 각 부분음 성분들의 강도값 계산 결과.

이를 그래프로 나타내면 아래의 그림 1과 같다.

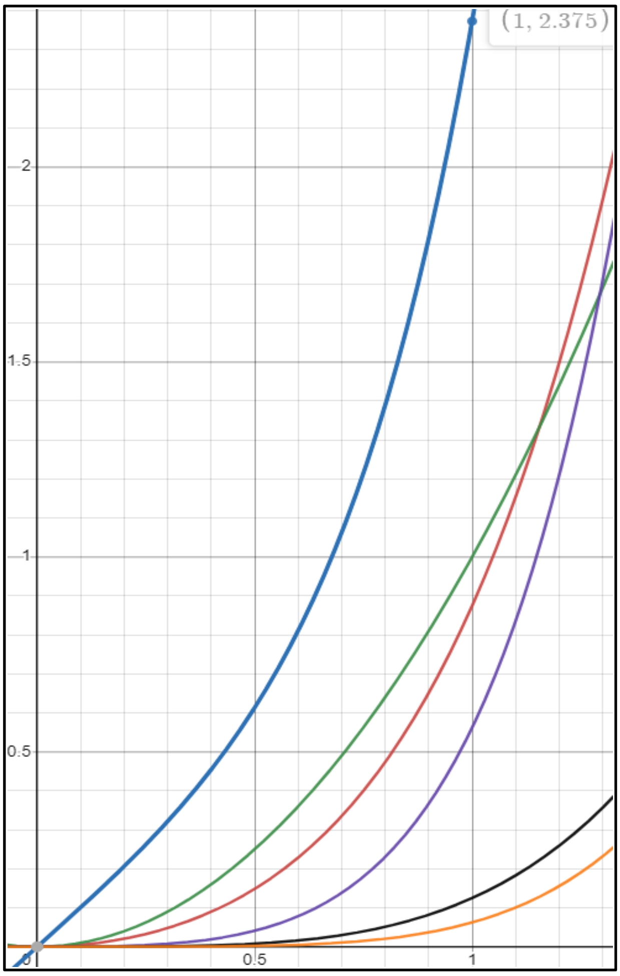


그림 1. 입력 신호인 정현파의 진폭(즉, 왜곡 지수)에 따른 출력 신호에서의 각 부분음 성분의 강도 변화 양상 그래프. 빨간색 곡선이 DC, 파란색 곡선이 cos x 성분, 초록색 곡선이 cos 2x 성분, 보라색 곡선이 cos 3x 성분, 검은색 곡선이 cos 4x 성분, 노란색 곡선이 cos 5x 성분.

다음 주제로 넘어가기 전에 정현파의 거듭제곱꼴이 주파수 영역이 아닌, 시간 영역에서의 모습은 어떤 형태를 띠는지 관찰해 보자. 시간 영역에서의 정현파의 거듭제곱은 매우 직관적이고 간단하게 예측이 가능하며, 규칙성이 명확하다.

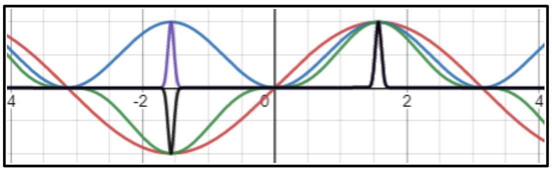


그림 2. 정현파의 거듭제곱을 시간 영역에서 나타낸 그래프.

그림 2에서 빨간색 선이 정현파(사인함수), 파란색 선이 정현파의 제곱, 초록색 선이 세제곱, 보라색 선이 정현파의 500제곱, 검은색 선이 501제곱이다. 정현파를 홀수 번 거듭제곱하면 양극성 신호(bipolar signal)이 되고, 짝수 번 거듭제곱하면 단극성 신호(unipolar signal)이 된다. 거듭제곱수의 홀, 짝 여부에 상관없이 거듭제곱수가 올라갈수록 신호의 순간 진폭의 변화율이 증가한다. 거듭제곱의 횟수가 무한대로 커지면 단극성 혹은 양극성 임펄스(impulse)와 같은 신호가 되어버린다. 정리하면, 정현파를 제곱하게 되면 시간 영역 상에서는 정현파 속 굴곡의 폭이 점점 좁아지는 양상을 띤다고 할 수 있다(입력 신호가 복합음 신호라 해도 신호 속 굴곡의 폭이 점점 좁아지는 모양을 띤다고 생각할 수 있다).

2) 입력신호가 복합음일 경우 찾을 수 있는 일반적 규칙들

이번에는 입력 신호가 정현파 둘 이상의 가산합성으로 이뤄진 복합음의 경우를 생각해 보자. 입력 신호를 구성하는 두 개의 정현파 성분을 각각 $A\cos a, B\cos b$라고 할 때, 입력 신호를 제곱하면,

$$\frac{1}{2}A^2(1+\cos 2a)+\frac{1}{2}B^2(1+\cos 2b)+AB\,(\cos(a+b)+\cos(a-b))$$

와 같은 결과가 나온다(만약 a와 b가 배수 관계에 놓여 있다면 출력 신호의 배음 구조는 매우 협화적으로(Harmonic) 형성된다). 단순 정현파의 거듭제곱보다는 매우 복잡한 결과가 나오게 되는데, 이는 입력 신호의 주파수 성분끼리 시간 영역 상에서 곱해지는 현상(위 식에서의 AB가 계수인 항에서 관찰된다) 때문에 발생하는 것이며, Miller Puckette은 자신의 저서[2]에서 이를 "**intermodulation(상호 변조)**"이라는 용어로 설명하고 있다. 아래에는 Supercollider코드로 작성한 복합음을 대상으로 하는 파형성형의 간단한 사례들을 보인다.

```
(
{
var n = 17;
a = Signal.newClear((2**n) + 1);
b = Buffer.alloc(s, (2**(n+1)), 1, bufnum: 1);
a.waveFill({|x| x**2}, -1, 1);
b.loadCollection(a.asWavetableNoWrap);
b.plot;
 Shaper.ar(
b, SinOsc.ar(1000, mul: 0.5)
+SinOsc.ar(2000, mul: 0.5), 1)
}.play;
)
```

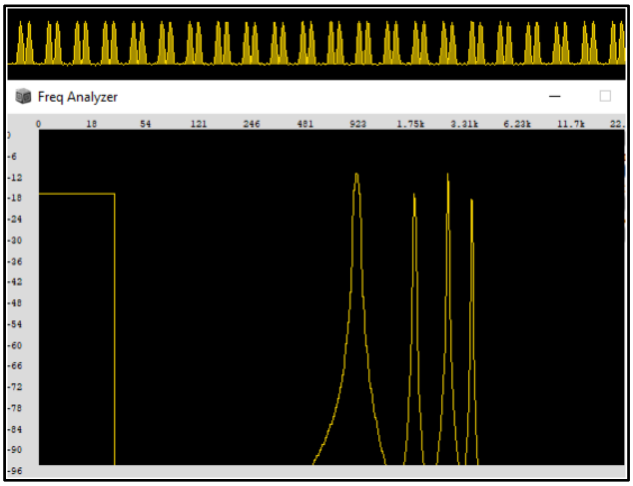


그림 3. x^2이 전달함수인 시스템의 입력 신호가 진폭이 0.5이고 각각의 주파수가 1000, 2000Hz인 두 정현파의 합인 경우의 출력 신호의 파형과 스펙트럼.

```
(
{
var n = 17;
a = Signal.newClear((2**n) + 1);
b = Buffer.alloc(s, (2**(n+1)), 1, bufnum: 1);
a.waveFill({|x| x**2}, -1, 1);
```

[2] The theory and technique of Electronic Music(2007)

```
b.loadCollection(a.asWavetableNoWrap);
b.plot;
 Shaper.ar(
b, SinOsc.ar(1000, mul: 0.333)
+SinOsc.ar(2000, mul:0.333)
+SinOsc.ar(3000, mul: 0.333), 1)
}.play;
)
```

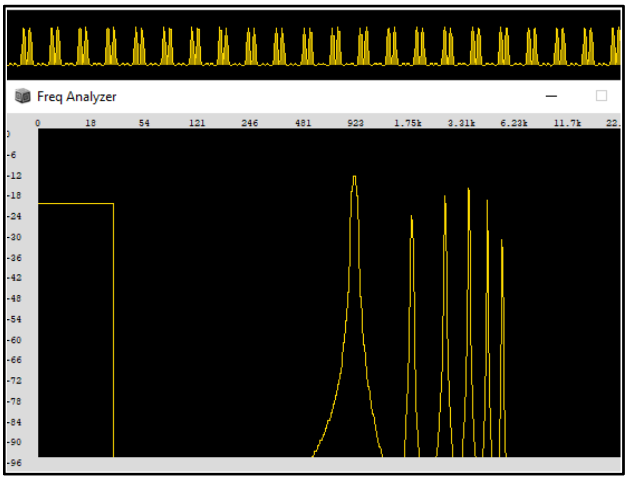


그림 4. x^2이 전달함수인 시스템의 입력 신호가 진폭이 0.333이고 각각의 주파수가 1000, 2000, 3000Hz인 세 정현파의 합인 경우의 출력 신호의 파형과 스펙트럼.

```
(
{
var n = 17;
a = Signal.newClear((2**n) + 1);
b = Buffer.alloc(s, (2**(n+1)), 1, bufnum: 1);
a.waveFill({|x| x**3}, -1, 1);
b.loadCollection(a.asWavetableNoWrap);
b.plot;
 Shaper.ar(b, SinOsc.ar(1000, mul: 0.5)
+SinOsc.ar(2000, mul:0.5), 1)
}.play;
)
```

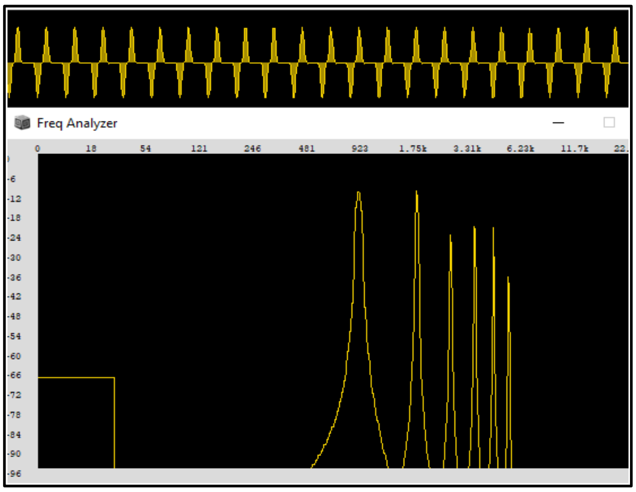


그림 5. x^3이 전달함수인 시스템의 입력 신호가 진폭이 0.5이고 각각의 주파수가 1000, 2000Hz인 두 정현파의 합인 경우의 출력 신호의 파형과 스펙트럼.

위와 같이 복합음을 대상으로 하는 파형성형을 전달함수가 N-제곱 형태인 시스템을 통해 수행할 때, 출력 신호를 예측하는 것은 그렇게 어렵지 않다. 문제는 코사인 함수들의 선형 합의 형태인 복합음을 통째로 거듭제곱 연산을 통해 항을 하나하나씩 곱셈해서 출력 신호의 성분을 계산하는 것은 매우 복잡한 계산 과정을 수반하게 된다. Dodge가 제시한 도표상의 숫자들은 **이항계수**(Binomial coefficient)들이며, "**이항정리**(Binomial theorem)"를 통해 이들을 쉽게 찾아낼 수 있다. 이를 조금 더 많은 항을 가진 다항식들에 대해 일반화하면 "**다항정리**(polynomial theorem)"를 유도할 수 있는데, 이 다항정리를 통해 아래와 같이 삼각 다항식의 완전 N-제곱 연산결과 속 각 항들의 계수를 비교적 쉽게 알아낼 수 있을 것이다. 아래의 예시는 항이 3개인 경우를 나타내고 있다.

삼각 다항식

"$(\mathrm{A}\cos a+\mathrm{B}\cos b+\mathrm{C}\cos c)^n$"

를 전개한 계산 결과 속의

"$(\mathrm{A}\cos a)^p \bullet (\mathrm{B}\cos b)^q \bullet (\mathrm{C}\cos c)^r$ "

항의 계수는 $\frac{n!}{p!q!r!}$이다(단, p+q+r=n).

앞서 살펴본 정현파 N-제곱의 일반화 식과 위에 서술한 다항정리를 이용하여 "복합음의 완전 N-제곱"의 1차적인 계산 과정을 예상해 본다면, "단순한 정현파들의 선형적 조합으

로 이뤄진 다항식 몇 개의 곱"이 된다. 그 다항식들 속의 각 정현파 성분(즉, 코사인 함수의 항)들끼리 서로 곱해지며 발생하는 링 변조의 결과들을 계산하면 된다.

이 방법으로 복합음의 완전 거듭제곱의 결과를 하나 계산해 보자. 예를 들어, 부분음이 3개인 복합음 입력 신호를 전달함수가 $f(x)=x^3$ 인 시스템에 부여한 결과를 계산해 보자. 입력 신호의 세 주파수 성분을 각각 1200, 2000, 4500Hz라고 정해 두고, 각각의 진폭들은 0.1, 0.5, 0.3이라 정해 보자. 이 상황을 수식으로 나타낸다면

$$(0.1cos(2\pi \bullet 1200t)+0.5cos(2\pi \bullet 2000t)+0.3cos(2\pi \bullet 4500t))^3$$

와 같은 형태가 된다. 여기서 나올 수 있는 항의 종류들을 모아 보면 총 10가지가 되며, 그 종류들은 아래와 같다.

1) $(0.1cos(2\pi \bullet 1200t))^1 \bullet (0.5cos(2\pi \bullet 2000t))^1 \bullet (0.3cos(2\pi \bullet 4500t))^1$

2) $(0.1cos(2\pi \bullet 1200t))^2 \bullet (0.5cos(2\pi \bullet 2000t))^1$

3) $(0.1cos(2\pi \bullet 1200t))^2 \bullet (0.3cos(2\pi \bullet 4500t))^1$

4) $(0.5cos(2\pi \bullet 2000t))^2 \bullet (0.3cos(2\pi \bullet 4500t))^1$

5) $(0.1cos(2\pi \bullet 1200t))^1 \bullet (0.5cos(2\pi \bullet 2000t))^2$

6) $(0.1cos(2\pi \bullet 1200t))^1 \bullet (0.3cos(2\pi \bullet 4500t))^2$

7) $(0.5cos(2\pi \bullet 2000t))^1 \bullet (0.3cos(2\pi \bullet 4500t))^2$

8) $(0.1cos(2\pi \bullet 1200t))^3$

9) $(0.5cos(2\pi \bullet 2000t))^3$

10) $(0.3cos(2\pi \bullet 4500t))^3$

식 5. 삼각다항식 $(0.1cos(2\pi \bullet 1200t)+0.5cos(2\pi \bullet 2000t)+0.3cos(2\pi \bullet 4500t))^3$ 을 전개했을 때 나올 수 있는 항의 종류들 10가지.

식 5의 1)에서 10)의 앞에 붙는 계수들을 각각 계산하여 식에 반영하면 아래와 같다.

$$(0.1cos(2\pi \bullet 1200t)+0.5cos(2\pi \bullet 2000t)+0.3cos(2\pi \bullet 4500t))^3$$

=

$$\frac{3!}{1!1!1!} \bullet (0.1cos(2\pi \bullet 1200t))^1 \bullet (0.5cos(2\pi \bullet 2000t))^1 \bullet (0.3cos(2\pi \bullet 4500t))^1$$

+

$$\frac{3!}{2!1!} \bullet (0.1cos(2\pi \bullet 1200t))^2 \bullet (0.5cos(2\pi \bullet 2000t))^1$$

+

$$\frac{3!}{2!1!} \bullet (0.1cos(2\pi \bullet 1200t))^2 \bullet (0.3cos(2\pi \bullet 4500t))^1$$

+

$$\frac{3!}{2!1!} \bullet (0.5cos(2\pi \bullet 2000t))^2 \bullet (0.3cos(2\pi \bullet 4500t))^1$$

+

$$\frac{3!}{2!1!} \bullet (0.1cos(2\pi \bullet 1200t))^1 \bullet (0.5cos(2\pi \bullet 2000t))^2$$

+

$$\frac{3!}{2!1!} \bullet (0.1cos(2\pi \bullet 1200t))^1 \bullet (0.3cos(2\pi \bullet 4500t))^2$$

+

$$\frac{3!}{2!1!} \bullet (0.5cos(2\pi \bullet 2000t))^1 \bullet (0.3cos(2\pi \bullet 4500t))^2$$

+

$$\frac{3!}{3!} \bullet (0.1cos(2\pi \bullet 1200t))^3$$

+

$$\frac{3!}{3!} \bullet (0.5cos(2\pi \bullet 2000t))^3$$

+

$$\frac{3!}{3!} \bullet (0.3cos(2\pi \bullet 4500t))^3$$

식 6. 식 5에서 얻은 항들 앞에 알맞은 계수를 계산하여 각 항들의 합의 형태로 구성된 삼각 다항식의 전개.

$\frac{3!}{1!1!1!}$=6 이고, $\frac{3!}{2!1!}$=3 이고, $\frac{3!}{3!}$=1 이다. 이를 반영하여 남은 항들의 곱셈 연산(단순 정현파끼리의 링 변조와도 같다고 할 수 있는)을 마저 수행하여 단순 정현파 성분들의 조합으로 설명할 수 있을 만큼 전개하는 과정을 통해 출력 신호의 주파수 성분들과 그 강도값들을 계산하는 과정을 아래에 보인다. 먼저 식 6의 전개식 부분의 10개의 항들 중 첫 번째 항을 단순 정현파 성분의 조합으로 설명될 때까지 완전히 계산하면,

$$0.0225(cos\,(2\pi \bullet 7700t)+cos\,(2\pi \bullet 1300t)$$
$$+cos(2\pi \bullet 5300t)+cos(2\pi \bullet 3700t))$$

이 되며, 0.225의 진폭을 가지는 7700, 5300, 3700, 1300Hz의 정현파 성분을 얻게 된다.

나머지 9개의 항들도 마저 계산하여, 삼각 다항식

$(0.1cos(2\pi\bullet 1200t)+0.5cos(2\pi\bullet 2000t)+0.3cos(2\pi\bullet 4500t))^3$

의 형태로 표현되는 파형성형의 최종 결과를 아래와 같이 보인다.

$0.0225(cos\,(2\pi\bullet 7700t)+cos\,(2\pi\bullet 1300t)$

$+cos(2\pi\bullet 5300t)+cos(2\pi\bullet 3700t))$

$+$

$0.00375cos(2\pi\bullet 400t)+0.0075cos(2\pi\bullet 2000t)$

$+0.00375cos(2\pi\bullet 4400t)$

$+$

$0.00225cos(2\pi\bullet 2100t)+0.0045cos(2\pi\bullet 4500t)$

$+0.00225cos(2\pi\bullet 6900t)$

$+$

$0.05625cos(2\pi\bullet 500t)+0.1125cos(2\pi\bullet 4500t)$

$+0.05625cos(2\pi\bullet 8500t)$

$+$

$0.0375cos(2\pi\bullet 1200t)+0.01875cos(2\pi\bullet 2800t)$

$+0.0375cos(2\pi\bullet 5200t)$

$+$

$0.0135cos(2\pi\bullet 1200t)+0.00675cos(2\pi\bullet 7800t)$

$+0.00675cos(2\pi\bullet 10200t)$

$+$

$0.0675cos(2\pi\bullet 2000t)+0.03375cos(2\pi\bullet 7000t)$

$+0.03375cos(2\pi\bullet 11000t)$

$+$

$0.00075cos(2\pi\bullet 1200t)+0.00025cos(2\pi\bullet 3600t)$

$+$

$0.09375cos(2\pi\bullet 2000t)+0.03125cos(2\pi\bullet 6000t)$

$+$

$0.02025cos(2\pi\bullet 4500t)+0.00675cos(2\pi\bullet 13500t)$

$=$

$0.00375cos(2\pi\bullet 400t)+$

$0.05625cos(2\pi\bullet 500t)+$

$0.05175cos(2\pi\bullet 1200t)+$

$0.0225cos(2\pi\bullet 1300t)+$

$0.16875cos(2\pi\bullet 2000t)+$

$0.00225cos(2\pi\bullet 2100t)+$

$0.01875cos(2\pi\bullet 2800t)+$

$0.00025cos(2\pi\bullet 3600t)+$

$0.0225cos(2\pi\bullet 3700t)+$

$0.00375cos(2\pi\bullet 4400t)+$

$0.13725cos(2\pi\bullet 4500t)+$

$0.0375cos(2\pi\bullet 5200t)+$

$0.03125cos(2\pi\bullet 6000t)+$

$0.00225cos(2\pi\bullet 6900t)+$

$0.03375cos(2\pi\bullet 7000t)+$

$0.0225cos(2\pi\bullet 7700t)+$

$0.00675cos(2\pi\bullet 7800t)+$

$0.05625cos(2\pi\bullet 8500t)+$

$0.00675cos(2\pi\bullet 10200t)+$

$0.03375cos(2\pi\bullet 11000t)+$

$0.00675cos(2\pi\bullet 13500t)$

식 7. 파형성형을 나타내는 삼각 다항식

$(0.1cos(2\pi\bullet 1200t)+0.5cos(2\pi\bullet 2000t)+0.3cos(2\pi\bullet 4500t))^3$

을 완전히 전개한 후 단순 정현파 성분의 합으로 나타낸 결과.

합성 결과로 총 21개에 달하는 많은 부분음들이 발생하는데, 이 부분음들의 주파수의 최대공약수(GCD)는 100Hz이다. 따라서 파형성형 후 출력된 신호를 청취할 때 우리는 기음(fundamental) 성분의 주파수를 100Hz로 삼게 될 것이다. 상기한 파형성형의 결과를 Supercollider 상에서 실제로 구현해 보면 아래와 같다.

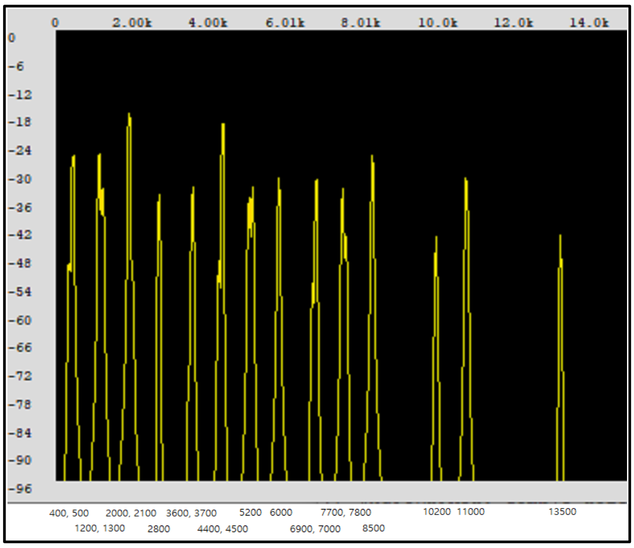


그림 6. Supercollider 상에서 구현된 $(0.1cos(2\pi \bullet 1200t)+0.5cos(2\pi \bullet 2000t)+0.3cos(2\pi \bullet 4500t))^3$ 형태의 파형성형의 결과(Linear Frequency Scale).

3) 입력 신호가 "<u>동일한 강도의 부분음 성분으로 구성된 협화적 복합음</u>"일 때의 특징적 규칙들

N-제곱 함수를 전달함수로 가지는 시스템에 소제목에 기술한 조건에 맞는 "동일한 강도의 부분음 성분으로 구성된 협화적인 복합음"의 신호가 입력 신호로 부여된다면, 흥미로운 패턴이 발견된다. 아래와 같은 규칙으로 완전제곱을 통해 협화적 복합음을 파형성형 한다고 가정해 보자.

$$(cos\theta+cos2\theta)^2$$
$$(cos\theta+cos2\theta+cos3\theta)^2$$
$$(cos\theta+cos2\theta+cos3\theta+cos4\theta)^2$$
$$(cos\theta+cos2\theta+cos3\theta+cos4\theta+cos5\theta)^2$$
$$(cos\theta+cos2\theta+cos3\theta+cos4\theta+cos5\theta+cos6\theta)^2$$
...

식 8. 협화적 복합음을 완전제곱하는 파형성형의 예시들.

이 중 첫 번째 줄의 전개 결과는 아래와 같은데,

$$0.5(2cos\theta+cos2\theta+2cos3\theta+cos4\theta+2)$$

이 표기를 다시 아래와 같이 축약해 계수 위주의 표현을 하기로 한다(가장 우측은 DC 성분이다).

0.5(2, 1, 2, 1, 2)

이런 형태로 상기한 식들의 계산 결과를 표현한다면 아래와 같다.

0.5(2, 1, <u>2</u>, 1, 2)

0.5(4, 3, 2, <u>3</u>, 2, 1, 3)

0.5(6, 5, 4, 3, <u>4</u>, 3, 2, 1, 4)

0.5(8, 7, 6, 5, 4, <u>5</u>, 4, 3, 2, 1, 5)

0.5(10, 9, 8, 7, 6, 5, <u>6</u>, 5, 4, 3, 2, 1, 6)

항상 항의 개수는 홀수 개이므로 정중앙의 항 하나를 특정할 수 있다(밑줄 참고). 아래에 작은 숫자들은 정중앙의 항을 기준으로 한 증감의 정도를 나타내고 있다.

0.5(2, 1, <u>2</u>, 1, 2)
+1 -1 -1 +1

0.5(4, 3, 2, <u>3</u>, 2, 1, 3)
+1 +1 -1 -1 -1 +2

0.5(6, 5, 4, 3, <u>4</u>, 3, 2, 1, 4)
+1 +1 +1 –1 –1 –1 –1 +3

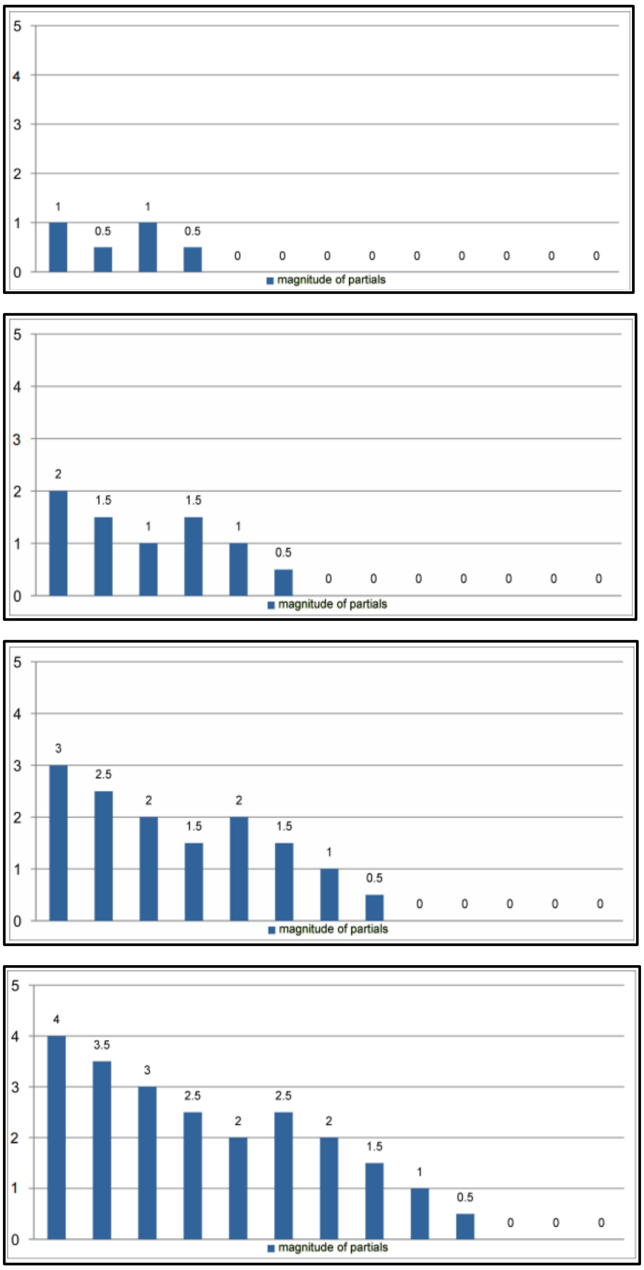
0.5(8, 7, 6, 5, 4, <u>5</u>, 4, 3, 2, 1, 5)
+1 +1 +1 +1 –1 –1 –1 –1 -1 +4

0.5(10, 9, 8, 7, 6, 5, <u>6</u>, 5, 4, 3, 2, 1, 6)
+1 +1 +1 +1 +1 –1 –1 –1 –1 -1 -1 +5

• • •

증감의 정도를 나타내는 작은 숫자들 속에서 규칙이 발견된다. 정중앙 항의 계수를 기준으로 좌측으로의 규칙은 처음 1

회만 –1이 되고, 그 이후는 모두 +1이 된다는 것이다. 우측으로의 규칙은 계속 –1이 되다가 가장 마지막에는 +n(단, n은 식 8에서 몇 번째 줄에 있는 식인지 나타내는 숫자이다)이 된다는 것이다(가장 우측의 숫자는 DC 성분의 강도를 나타내는 숫자임을 밝힌다). 이 정보를 그래프로 나타내 보면 아래와 같다.



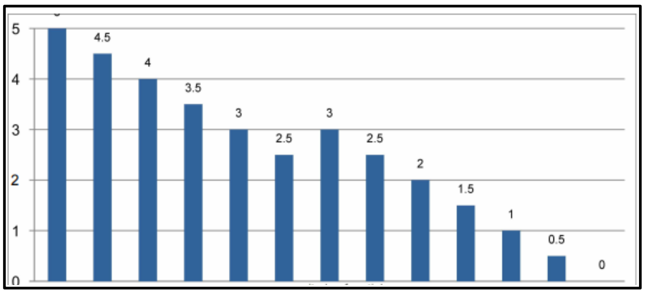


그림 7. 식 8 속의 파형성형 결과를 주파수 영역에서 표현한 그래프.

그림 7을 관찰해 보면 계수들만 놓고 보았을 때보다 더 규칙성이 명확히 드러난다. 발생하는 주파수 성분 중 DC 성분을 제외하고 모든 부분음을 기음부터 차례로 나열했을 때, 앞의 절반과 뒤의 절반의 모양이 비율만 다를 뿐, 똑같은 형태를 띠고 있음을 알 수 있다.

이번에는 완전 세제곱을 통해 협화적 복합음 입력 신호를 파형성형하는 경우에 출력되는 신호에서의 규칙을 알아보자.

$$(cos\theta+cos2\theta)^3$$

$$(cos\theta+cos2\theta+cos3\theta)^3$$

$$(cos\theta+cos2\theta+cos3\theta+cos4\theta)^3$$

$$(cos\theta+cos2\theta+cos3\theta+cos4\theta+cos5\theta)^3$$

$$(cos\theta+cos2\theta+cos3\theta+cos4\theta+cos5\theta+cos6\theta)^3$$

…

식 9. 협화적 복합음을 완전 세제곱하는 파형성형의 예시들.

식 9에서의 삼각 다항식들을 전개한 결과를 이번에도 계수 위주로 동일 규칙 하에 축약 표현해 보자.

0.25(9, 9, 4, 3, 3, 1, 3)

0.25(21, 21, 19, 12, 9, 7, 6, 3, 1, 9)

0.25(39, 39, 37, 33, 24, 19, 15, 12, 10, 6, 3, 1, 18)

0.25(63, 63, 61, 57, 51, 40, 33, 27,
22, 18, 15, 10, 6, 3, 1, 30)

0.25(93, 93, 91, 87, 81, 73, 60, 51, 43,
36, 30, 25, 21, 15, 10, 6, 3, 1, 45)

이번에는 가장 우측의 숫자부터 시작하여 올라가며 차례로 증감 정도를 계산한다. 구성 항의 계수들끼리의 단순 증감으로는 경향성을 정확히 파악할 수 없어 계수들의 단순 증감 경향에서 한 번 더 증감 정도를 파악한 2차적 계산 결과를 통해 규칙을 알아본다.

0.25(9, 9, 4, 3, 3, 1, 3)

+0 +5 +1 –0 +2 -2

-5 +4 +1 –2 +4

0.25(21, 21, 19, 12, 9, 7, 6, 3, 1, 9)

+0 +2 +7 +3 +2 +1 +3 +2 -8

-2 -5 +4 +1 +1 -2 *+1* +10

0.25(39, 39, 37, 33, 24, 19, 15, 12, 10, 6, 3, 1, 18)

+0 +2 +4 +9 +5 +4 +3 +2 +4 +3 +2 –17

-2 -2 -5 +4 +1 +1 +1 -2 *+1 +1* +19

0.25(63, 63, 61, 57, 51, 40, 33, 27, 22, 18, 15, 10, 6, 3, 1, 30)

+0 +2 +4 +6 +11 +7 +6 +5 +4 +3 +5 +4 +3 +2 –29

-2 -2 -2 -5 +4 +1 +1 +1 +1 -2 *+1 +1 +1* +31

0.25(93,93,91,87,81,73,60,51,43,36,30,25,21,15,10,6,3,1,45)

+0 +2 +4 +6 +8 +13 +9 +8 +7 +6 +5 +4 +6 +5 +4 +3+2 -44

-2 –2 –2 –2 –5 -4 +1 +1 +1 +1 +1 -2 *+1 +1 +1 +1* +46

…

2차적인 증감 수치를 관찰했을 때, 중앙의 n(식 9에서 몇 번째 줄에 위치한 식인지 나타내는 수)개를 +1로 채우게 되며(밑줄 참고) 좌측에는 –5, -4가 한 번씩 나타난 후(점선 밑줄 참고) 나머지 자리들을 –2로 모두 채우게 된다(이탤릭체로 표기됨). 우측으로는 –2가 한 번 나타난 후(점선 밑줄 참고) 가장 우측 자리 하나를 제외한 나머지 자리를 +1로 채우면 된다(이탤릭체로 표기됨). DC 성분의 강도값은 모두 3의 배수로 이루어져 있는데, 입력신호의 부분음 성분이 하나씩 늘수록 "3에 곱해지는 수"가 규칙을 가진 채 늘어난다(1, 3, 6, 10, 15… 와 같은데 계차수열 형태이다). 이 정보 역시 그래프로 나타내 보면 아래와 같다.

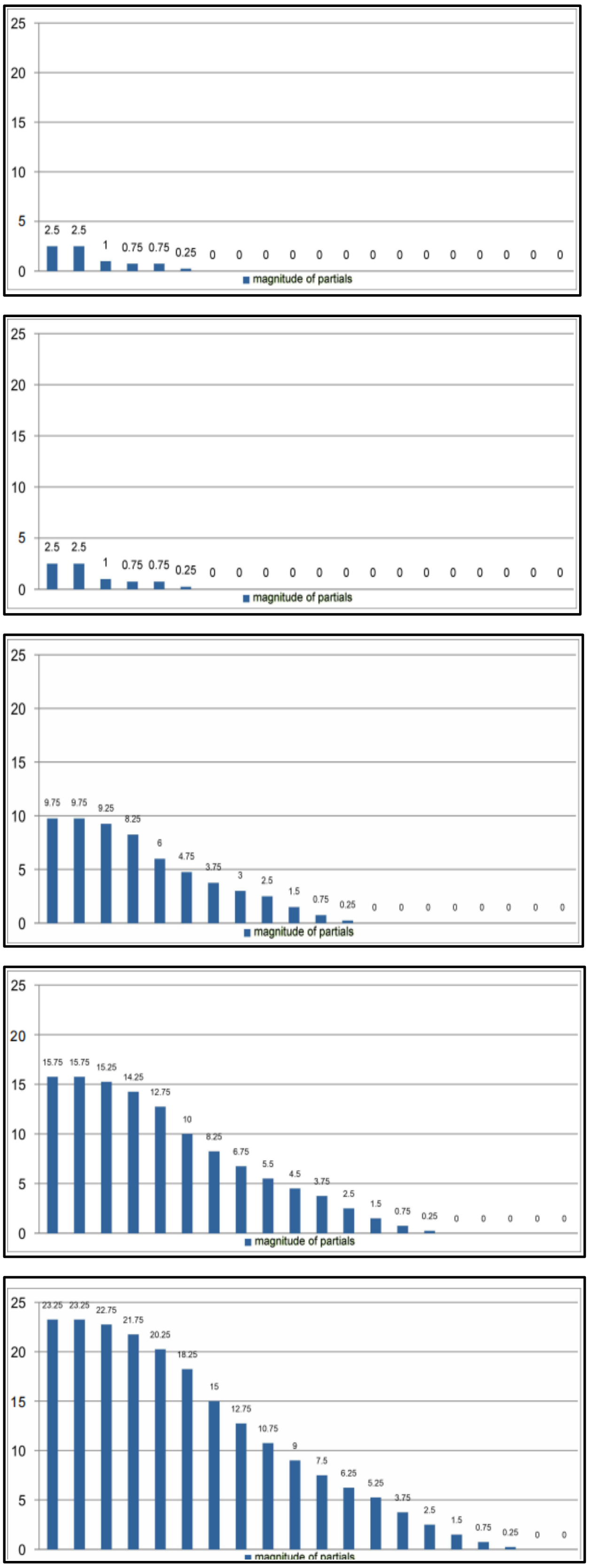


그림 8. 식 9 속의 파형성형 결과를 주파수 영역에서 표현한 그래프.

그림 7에서의 그래프와는 다르게 고배음 방향으로 가면서 중간에 일시적인 증가함 없이 계속 단조 감소함을 알 수 있다.

매클로린 급수로 해석 가능한 전달함수를 가지는 시스템

1) 테일러 급수와 매클로린 급수

이제 다양한 입력 신호에 대해 N-제곱 함수를 전달함수로 가지는 시스템의 출력 신호를 해석하는 방법을 바탕으로 몇 가지의 비선형 전달함수를 가지는 시스템을 해석하는 방법을 알아볼 것이다. 이를 위해서는 먼저 "**테일러 급수**(Taylor Series)"와 "**매클로린 급수**(Maclaurin Series)"를 알아야 한다. 아래는 테일러 급수의 정의를 나타내고 있다.

"함수 f(a)가 $a \in R$에서 여러번 미분 가능할 때,
다항함수들의 선형 합의 형태로 f(a)를 근사한 식을
*"**테일러 급수**"라고 부른다."*

$$\mathrm{T}_f(x)=\sum_{n=0}^{\infty}\frac{f^{(n)}(a)}{n!}(x-a)^n$$

$$=f(a)+f'(a)(x-a)+\frac{1}{2}f''(a)(x-a)^2+\frac{1}{6}f'''(a)(x-a)^3+\dots$$

식 10. 테일러 급수의 정의.

식 10에서 특별히 a=0일 때의 테일러 급수를 **매클로린 급수**라고 부른다.

$$\mathrm{M}_f(x)=\sum_{n=0}^{\infty}\frac{f^{(n)}(0)}{n!}(x)^n$$

$$=f(0)+f'(0)x+\frac{1}{2}f''(0)x^2+\frac{1}{6}f'''(0)x^3+\dots$$

식 11. 매클로린 급수의 정의.

매클로린 급수를 이용하여 대표적인 비선형 함수인 사인함수를 다항함수의 선형적 합의 형태로 표현하면 아래와 같다.

$$\sin x=x-\frac{x^3}{3!}+\frac{x^5}{5!}-\frac{x^7}{7!}+\dots\dots+(-1)^n\frac{x^{2n+1}}{(2n+1)!}+\dots\dots$$

식 12. 사인함수를 매클로린 급수 형태로 표현한 식.

만약 사인함수가 전달함수인 경우, 식 12에서의 미지수 x의 자리에 정현파를 나타내는 코사인함수를 대입하여 각 항을 "정현파의 N-제곱" 형태로 만들어 전술한 방법을 이용하여 파형성형의 최종 결과를 해석할 수 있다. 본 연구에서는 특별히 삼각함수들 중에서 특기할 만한 결과를 낳는 함수($y=sinx, y=tanx, y=arctanx, y=tanhx$) 몇 가지를 전달함수로 가지는 시스템을 해석해 보고, 마지막으로 몇 종류의 비선형 전달함수들이 직, 병렬로 조합된 임의의 시스템을 해석하는 한 예시를 보이기로 한다. 각각의 함수에 입력 신호로 정현파를 부여한 후 출력된 신호를 시간 영역과 주파수 영역에서 각각 관찰하고, 직접 이를 구현할 수 있는 Supercollider 코드를 제시한 다음 전달함수의 개형을 필요한 범위 안에서 구현하기 위해 필요한 매클로린 급수의 항이 비교적 적은 함수의 경우에는 파형성형 결과 발생하는 각 부분음 성분들의 강도값을 직접 구해볼 것이다.

2) 기본적 비선형 함수들의 전달함수화

[1] $y=sinx$의 경우

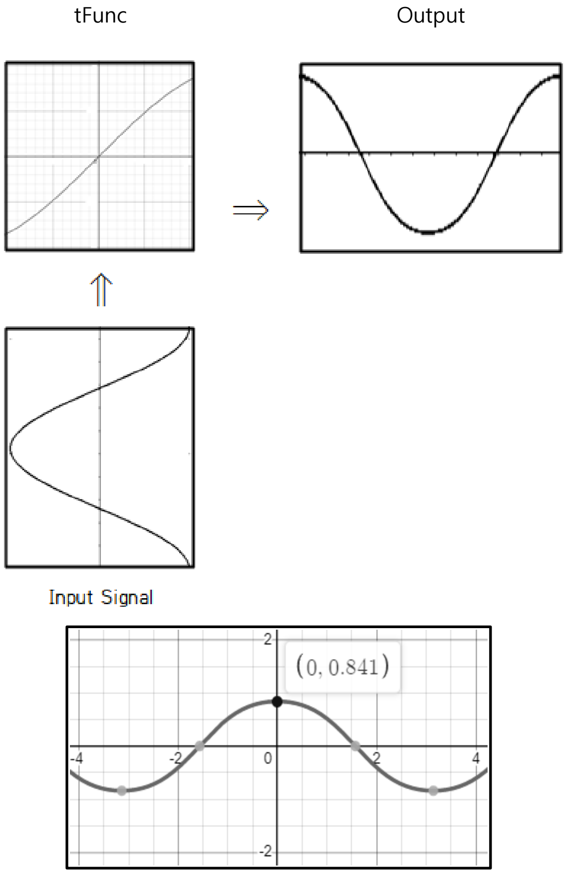


그림 9. $y=sin(cos\,x)$의 시간 영역에서의 그래프와 이를 얻는 과정.

상기한 **사인함수**($y=sinx$)가 전달함수인 경우를 해석해 보자. 앞서 언급된 식 12를 이용하여 사인함수 형태의 전달함수를 통한 파형성형 시스템의 단위 정현파 입력 신호에 대한 출력 신호를 계산하는 식을 만들면 아래와 같다. 아래의 식을 통해 전달함수가 사인함수일 경우, 더 이상 대역 제한적인 출력 신호가 나오지 않음을 알 수 있다(정확히 말하면 대역 제한적 신호가 무수히 모여서 대역 제한적이지 않게 된다고 설명할 수 있다).

$$sin(cos\ x) = cos\,x - \frac{(cos\,x)^3}{3!} + \frac{(cos\,x)^5}{5!} - \frac{(cos\,x)^7}{7!}$$

$$+ \ldots\ldots + (-1)^n \frac{(cos\,x)^{2n+1}}{(2n+1)!} + \ldots\ldots$$

$$= cos\,x - \frac{1}{3!\bullet 4}(3cos\,x + cos\,3x)$$

$$+ \frac{1}{5!\bullet 16}(10cosx + 5cos3x + cos5x)$$

$$- \frac{1}{7!\bullet 64}(35cosx + 21cos3x + 7cos5x + cos7x)$$

$$+ \ldots\ldots$$

$$0.8802083cos\,x - 0.0390625cos\,3x + 0.00052083cos\,5x + \ldots$$

식 13. 사인함수가 전달함수인 시스템을 이용한 파형성형 결과를 계산하는 수식(결과는 세 번째 항까지만을 합한 근삿값이다).

식 13 속의 계산 결과를 보면 홀수 번째 배음들만이 출력 신호에서 관찰되고 있음을 알 수 있다. 이를 주파수 영역에서 관찰하면 아래와 같은 결과를 얻게 된다(음수 크기의 강도값이 나오지만, 스펙트럼 상에서는 양수값으로 표현되어 나온다).

```
(
{
	SinOsc.ar(100, mul:1).sin;
}.play;
)
```

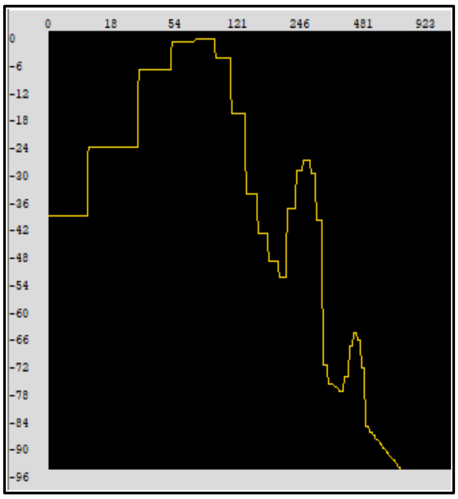
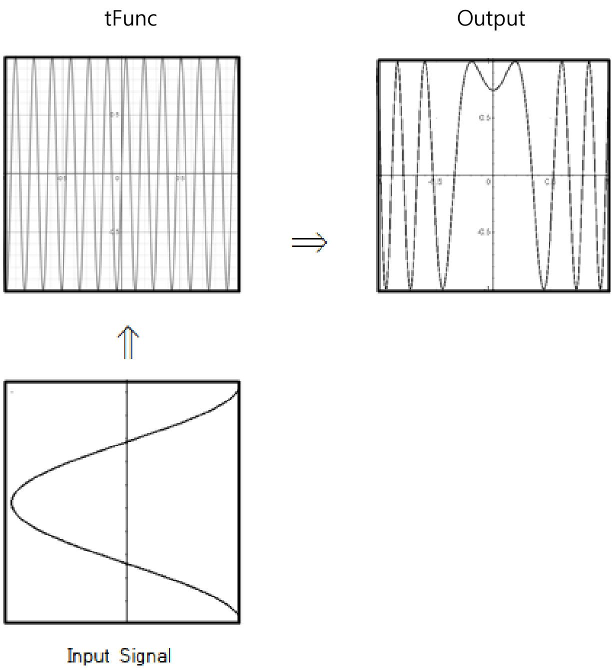
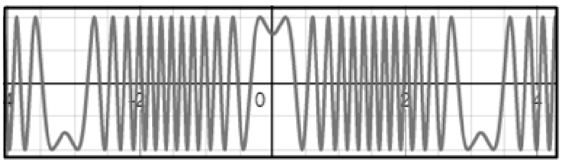


그림 10. 그림 9에서의 파형을 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). 입력한 정현파의 주파수는 100Hz이다.

만약 전달함수가 단순한 사인함수의 형태가 아니라 조금 더 주기가 짧은 $y=sin40x$과 같은 형태라면, 아래와 같이 더 다채로운 주파수 성분들을 포함하는 파형을 만들어 낼 수 있으며, 이 역시 식 13의 방법과 유사한 계산 과정을 통해 출력 신호의 특성을 분석할 수 있다. 다만 $y=sin40x$이라는 전달함수

를 필요한 범위 속에서 제대로 구현하기 위해서는 매클로린 급수 속의 항이 적어도 수십 개 정도 필요하며, 항의 개수가 부족한 상태에서 계산을 하면 실제 출력 신호에서의 결과와 상당히 괴리된 결과를 얻게 된다(거시적인 경향성 자체도 얻을 수 없을 정도이다). 아래에 파형성형의 과정과 그 결과의 일부를 보인다.





```
(
{
	SinOsc.ar(100, mul:40).sin;
}.play;
)
```

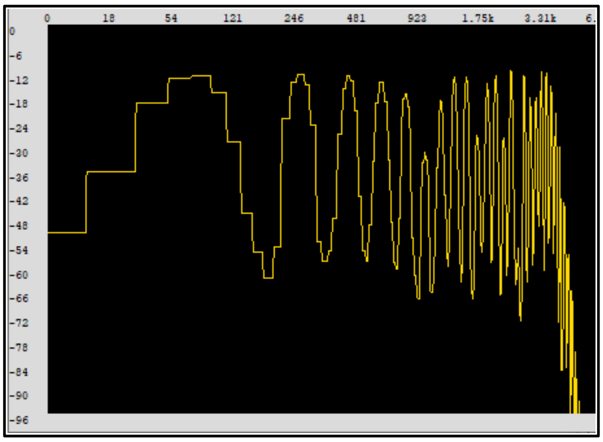
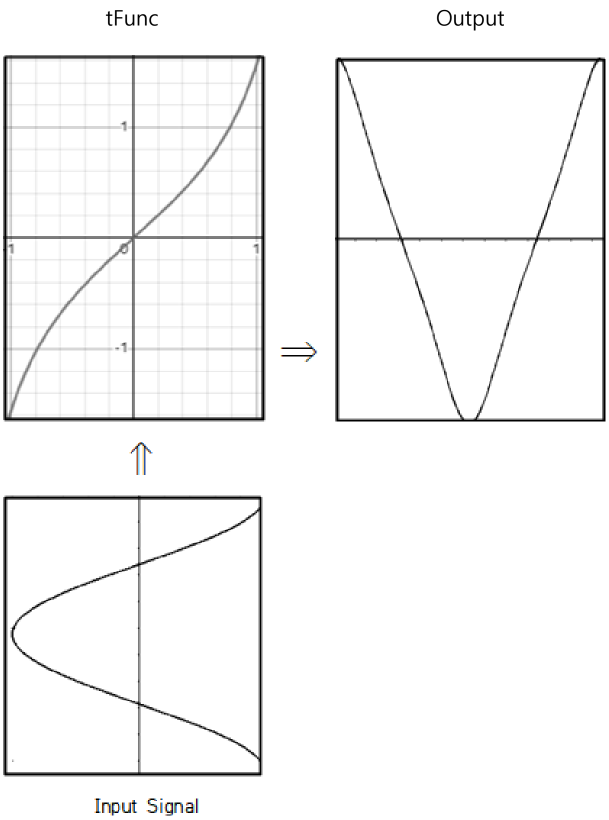


그림 11. 전달함수가 $y=sin40x$의 형태인 시스템을 통과한 주파수가 100Hz인 정현파의 시간 영역에서의 모습을 얻는 과정과 주파수 영역에서의 모습 (Logarithmic Frequency Scale).

[2] $y=tanx$의 경우



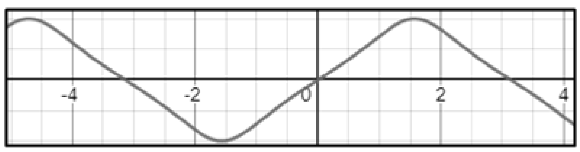


그림 12. $y=tan(\cos x)/1.557$의 시간 영역에서의 그래프와 이를 얻는 과정(단, /1.557은 진폭의 정규화를 위한 과정이다).

탄젠트 함수($y=tanx$)는 위와 같이 거시적으로는 삼각파를 닮았지만 변곡점들이 있고, 모서리가 둥근 형태의 흥미로운 파형을 단위 정현파 입력 신호에 대한 출력 신호로 만들어 준다. 탄젠트 함수를 매클로린 급수의 형태로 나타내면 아래와 같다. 그리고 아래의 매클로린 급수 속 변수의 자리에 코사인함수를 대입하여 단위 정현파 입력에 대한 파형성형을 계산한 결과까지 보인다.

$$tanx=\sum_{n=1}^{\infty}\frac{((-4)^{n}-(-16)^{n})\bullet B_{2n}}{(2n)!}x^{2n-1}$$

$$=x+\frac{1}{3}x^{3}+\frac{2}{15}x^{5}+\frac{17}{315}x^{7}+\ldots$$

$$tan(cosx)=cosx+\frac{1}{3}cos^{3}x+\frac{2}{15}cos^{5}x+\frac{17}{315}cos^{7}x+\ldots=$$

$$\cos x$$

$$+\frac{1}{3\bullet 4}(3\cos x+\cos 3x)$$

$$+\frac{2}{15\bullet 16}(10\cos x+5\cos 3x+\cos 5x)$$

$$+\frac{17}{315\bullet 64}(35\cos x+21\cos 3x+7\cos 5x+\cos 7x)$$

$$+\ldots$$

$$1.3\cos x+0.125\cos 3x+0.0083\cos 5x+\ldots$$

식 14. 탄젠트 함수를 매클로린 급수 형태로 표현한 것(B는 베르누이 수열[3]이다)과 이를 이용해 계산한 파형성형의 결과(결과는 세 번째 항까지만을 합한 근삿값이다).

식 14 속의 결과를 통해 탄젠트 함수를 전달함수로 갖는 시스템도 출력 신호에서 홀수 번째 배음들만을 관찰할 수 있다는 결과를 얻을 수 있다. 단, $y=tan(cosx)$의 계산 결과상 출력 신호의 진폭이 1.557이므로 청취 전에 진폭을 정규화(normalize)해주는 작업이 필요하다.

```
(
{
	SinOsc.ar(100, mul:1).tan/1.557;
}.play;
)
```

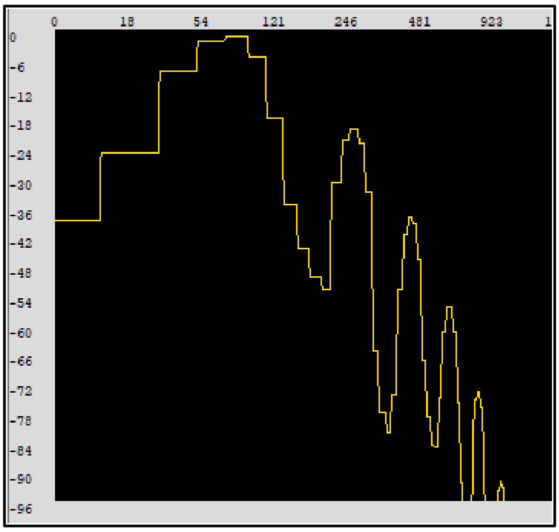


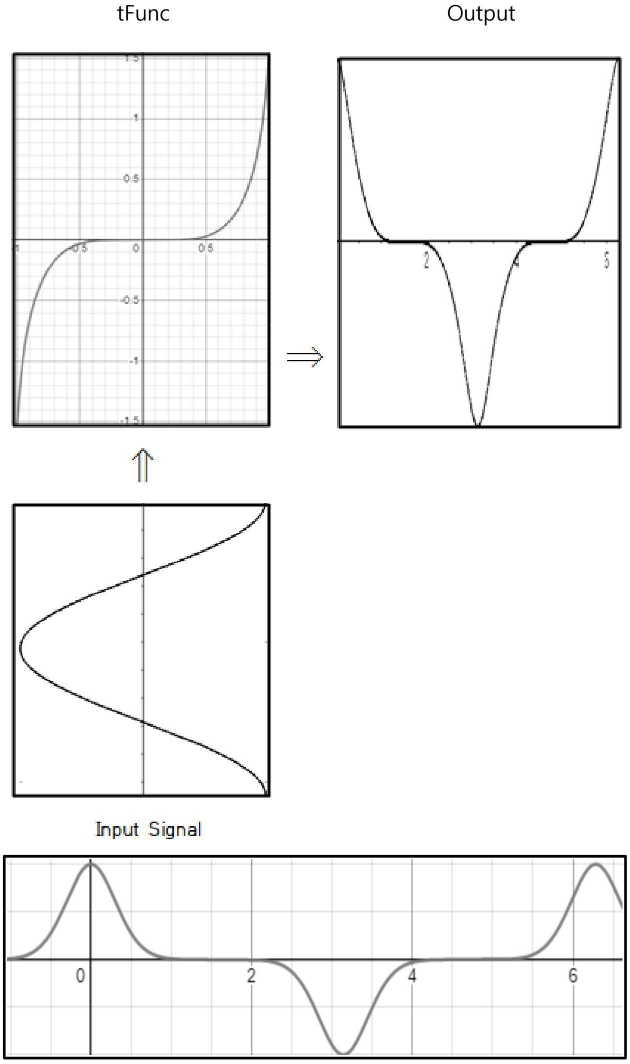
그림 13. 그림 12에서의 파형을 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). 입력한 정현파의 주파수는 100Hz이다.

만약 탄젠트 함수로 많은 양의 배음을 만들고 싶다면 탄젠트 함수의 변수 x를 $y=tan\,(x^{5})$와 같이 거듭제곱꼴로 만들어 전달함수로 이용하면 된다. 아래에 예시를 보인다.

---

[3] 탄젠트, 코탄젠트, 쌍곡탄젠트 등의 함수의 테일러 전개식의 각 항의 계수들 속에 포함된 수열이다. 이 수열은 주로 B_{2n}이라는 형태로 표기되는데, 이 이유는 제 3항 이상의 홀수 항이 모두 0이라는 성질이 있기 때문이다. 베르누이 수열의 일반항은 수학자 야코프 베르누이(Jacob Bernoulli)에 의해 다음과 같다고 알려져 있다.

$$B_{n}=\sum_{k=0}^{n}\frac{1}{k+1}\sum_{r=0}^{k}{}_{k}C_{r}(-1)^{r}r^{n}$$



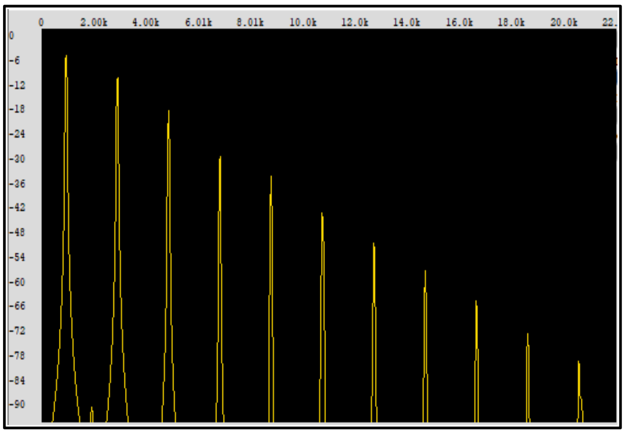


그림 14. $y=\frac{(tan(cosx)^{5})}{1.557}$의 시간 영역에서의 그래프를 얻는 과정과 이를 주파수 영역에서 관찰한 결과(Linear Frequency Scale). 입력한 정현파의 주파수는 1000Hz이다.

$y=tan\,((cos\,x)^{5})$의 매클로린 급수에서의 두 번째 항까지를 포함하여 근사한 형태로 파형성형의 결과를 계산하면 아래의 식 15와 같은 결과를 얻게 되고, 결과 속 계수들을 정규화하여 스펙트럼 상에 표현한 것이 그림 14이다.

$$tan((cos\,x)^{5})$$
$$=0.75592cos\,x+0.414326cos\,3x+0.123596cos\,5x$$
$$+0.02777cos\,7x+0.009256cos\,9x+0.002136cos\,11x$$
$$+0.000305cos\,13x+0.00002cos\,15x$$

식 15. $y=tan\,((cos\,x)^{5})$를 계산하여 얻을 수 있는 파형성형의 결과(단, 결과는 $y=tan\,((cos\,x)^{5})$의 매클로린 전개식의 두 번째 항까지만을 포함하여 근사한 값이다).

```
(
{
var n = 17;
a = Signal.newClear((2**n) + 1);
b = Buffer.alloc(s, (2**(n+1)), 1, bufnum: 1);
a.waveFill({|x| x**5}, -1, 1);
b.loadCollection(a.asWavetableNoWrap);
b.plot;

Shaper.ar(
b, SinOsc.ar(1000, 0, mul: 1), 1).tan/1.557;
}.play;
)
```

[3] $y=arctanx$의 경우

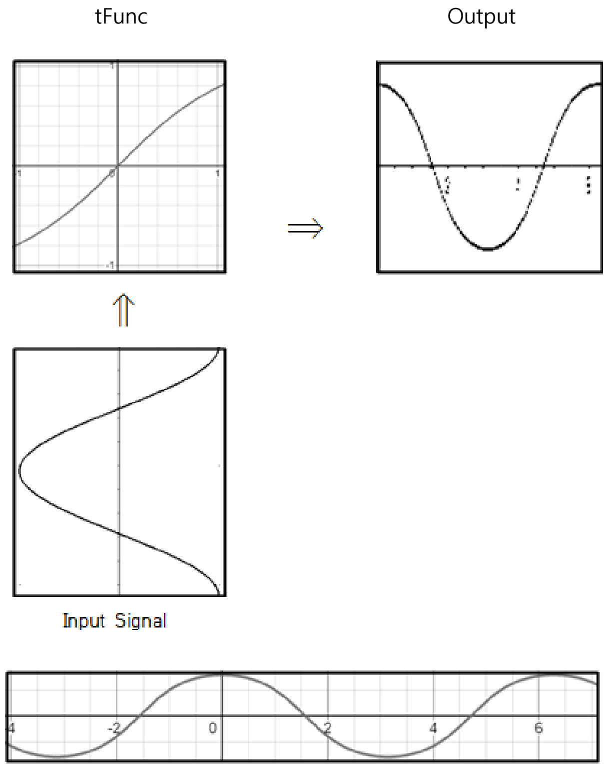


그림 15. $y=arctan(\cos x) \cdot 4/\pi$의 시간 영역에서의 그래프와 이를 얻는 과정(뒤에 붙은 $4/\pi$는 진폭을 1로 맞추기 위해 진행된 진폭의 정규화를 위한 숫자다).

앞서 언급된 탄젠트 함수의 역함수인 **아크탄젠트 함수**($y=arctanx$)를 매클로린 급수로 표현하면 아래와 같다. 그리고 파형성형의 결과 역시 간단히 계산하는 과정을 보인다.

$$arctan\,x=\sum_{n=0}^{\infty}\frac{(-1)^n x^{2n+1}}{2n+1}=x-\frac{x^3}{3}+\frac{x^5}{5}-\frac{x^7}{7}+\ldots\ldots\ (|x|\le 1)$$

$$arctan(cosx)$$

$$=\cos x-\frac{1}{3\cdot 4}(3\cos x+\cos 3x)$$

$$+\frac{1}{5\cdot 16}(10\cos x+5\cos 3x+\cos 5x)$$

$$-\frac{1}{7\cdot 64}(35\cos x+21\cos 3x+7\cos 5x+\cos 7x)$$

$$+\ldots$$

$$=0.796875\cos x-0.0677083\cos 3x$$

$$-0.003125\cos 5x-0.002232\cos 7x+\ldots$$

식 16. 아크탄젠트 함수를 매클로린 급수 형태로 표현한 것과 단위 정현파 입력 신호에 대한 파형성형의 결과(계산 결과는 네 번째 항까지 포함하여 계산한 근삿값이며, 여기서도 음수 크기의 강도값이 나오지만, 스펙트럼 상에서는 양수값으로 표현되어 나온다).

아크탄젠트 함수의 매클로린 전개식은 사인함수의 매클로린 전개식과 비슷한 형태를 띤다. 다른 점은 각 항의 분모가 계승(Factorial)의 형태를 띠지 않는다는 점 정도와 전개식에서의 정의역이 추가되었다는 점 정도이다. 따라서 사인함수를 전달함수로 쓰는 시스템의 단순 정현파에 대한 출력 신호와 각 주파수 성분들의 강도만 다를 뿐 같은 성분을 공유하고 있다고 볼 수 있다.

```
(
{
	SinOsc.ar(100, mul:1).atan*4/pi;
}.play;
)
```

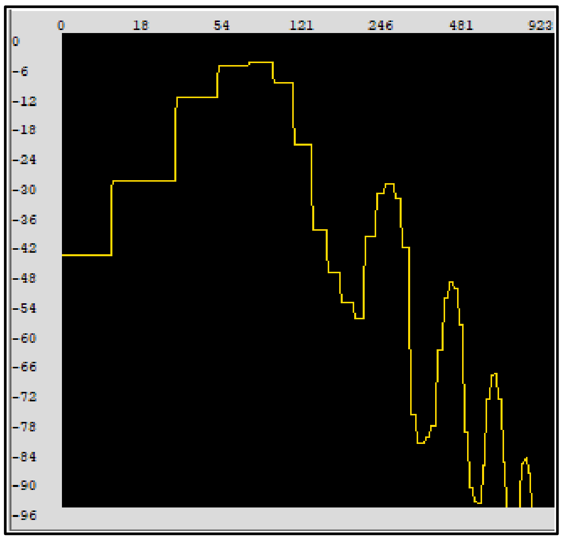
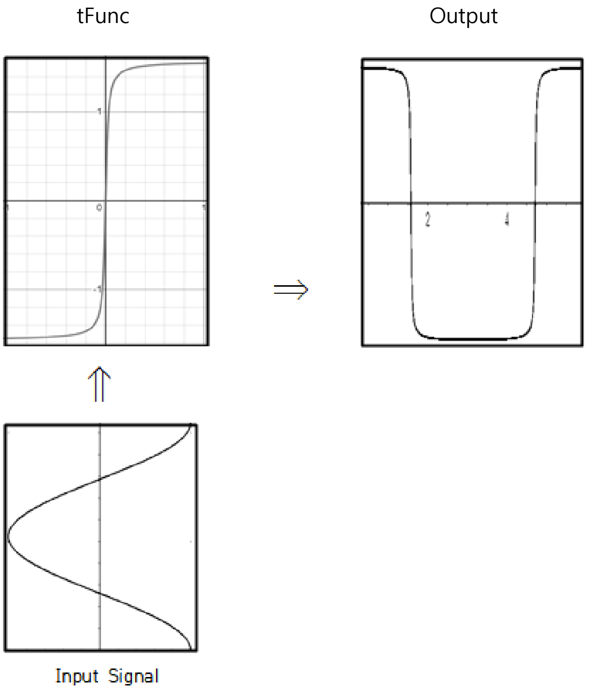
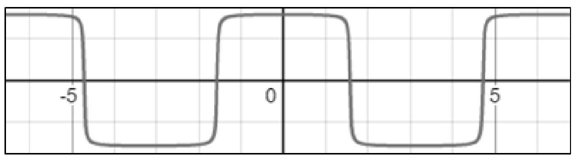


그림 16. 그림 15에서의 파형을 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). 입력한 정현파의 주파수는 100Hz이다.

이처럼 아크탄젠트 함수의 기본형을 전달함수로 이용했을 때에는 다소 단조로운 듯한 결과를 만들어내지만, 변형된 아크탄젠트 함수를 이용하면 흥미로운 출력 신호를 만들어 낼 수 있다. 먼저 $y=arctan\,50x$와 같이 전달함수로 이용될 아크탄젠트 함수의 변수 x 앞에 임의의 자연수 계수가 붙는 경우를 아래에 소개한다.






```
(
{
        SinOsc.ar(100, mul:50).atan/1.551;
}.play;
)
```

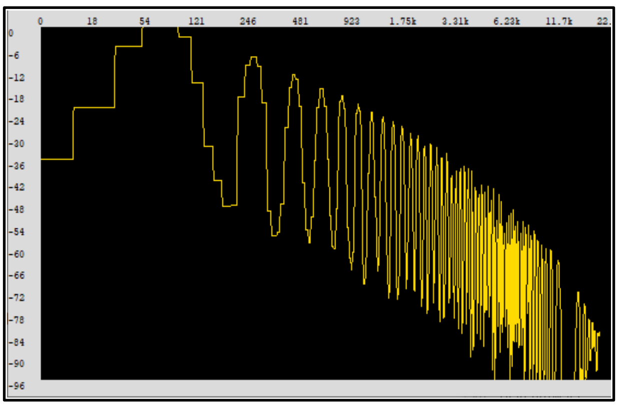


그림 17. $y=arctan(50cos\,x)/1.551$ 의 시간 영역에서의 그래프와 이를 얻어내는 과정(뒤에 붙은 /1.551은 진폭을 1로 맞추기 위한 정규화를 위한 숫자이다) 과 이를 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). 아주 많은 양의 부분음을 볼 수 있다. 입력한 정현파의 주파수는 100Hz이다.

아크탄젠트 전달함수 속의 변수 x 앞에 임의의 계수가 붙는 경우, 단순 정현파 입력 신호가 파형성형되어 출력될 때에 모서리가 다소 둥근 사각파와 비슷한 모양으로 찌그러지게 된다. 이 계수가 커질수록 왜곡의 정도(모서리 각짐의 정도)는 더욱 심해지며, 자연스럽게 많은 양의 부분음들을 추가적으로 발생하게 한다.

그리고 $y=arctan(50cos\,x)$ 를 이용한 파형성형 결과를 매클로린 급수를 통해 계산한 결과는 아래와 같다.

$$arctan(50cos\,x)$$

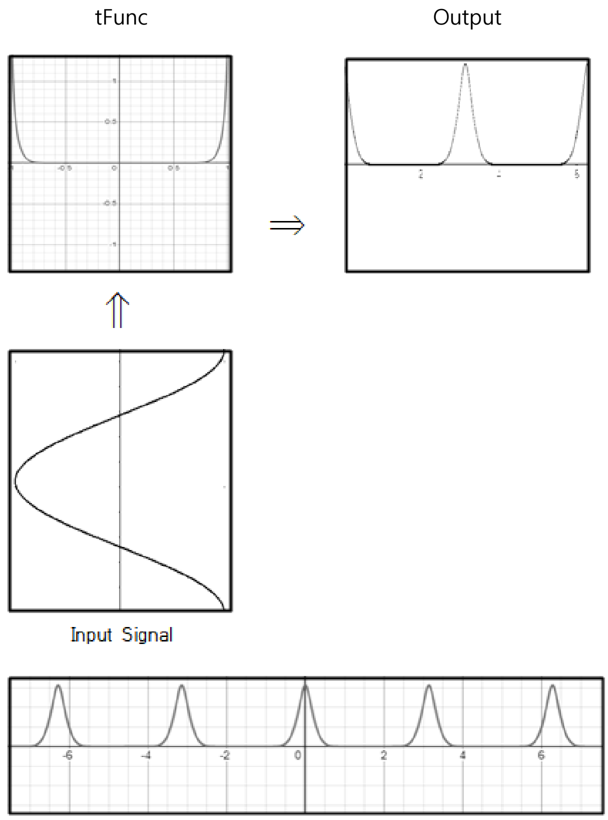
$$=-60996096825cos\,x-36601572916.6cos\,3x$$

$$-12203125000cos\,5x-1743861607.142857cos\,7x$$

$$+...$$

식 17. $y=arctan(50cos\,x)$ 로 표현되는 파형성형의 결과를 매클로린 급수를 이용해 계산한 결과(단, 매클로린 전개식의 4번째 항까지를 포함하여 계산한 근삿값이다. 그럼에도 불구하고 $y=arctan(50cos\,x)$ 는 ±1 범위 안에서의 그래프의 형태를 제대로 표현하기 위해 비교적 많은 개수의 매클로린 급수의 항들을 필요로 하는데 이 때문에 계산 결과 상에서 주파수 성분 강도값들의 거시적 경향성의 관찰 정도는 가능하나, 다른 함수들에서의 계산 결과보다 강도값들의 오차가 다소 크다는 사실과, 여기서도 음수 강도값들이 나옴 역시 일러둔다).

다음으로는 아크탄젠트 함수 속 변수 x가 N-제곱꼴이 될 때를 알아본다. 이 경우, 홀수 거듭제곱인지, 짝수 거듭제곱인지의 여부가 매우 중요해지는데, 우선 짝수 거듭제곱인 $y=arctan(x^{20})$의 경우를 알아보자.




```
(
{
var n = 17;
a = Signal.newClear((2**n) + 1);
b = Buffer.alloc(s, (2**(n+1)), 1, bufnum: 1);
a.waveFill({|x| x**20}, -1, 1);
b.loadCollection(a.asWavetableNoWrap);
b.plot;

Shaper.ar(
b, SinOsc.ar(100, 0, mul: 1), 1).atan*4/pi;
}.play;
)
```

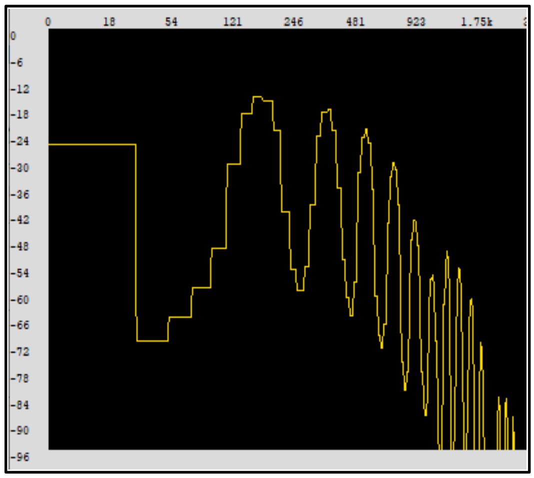
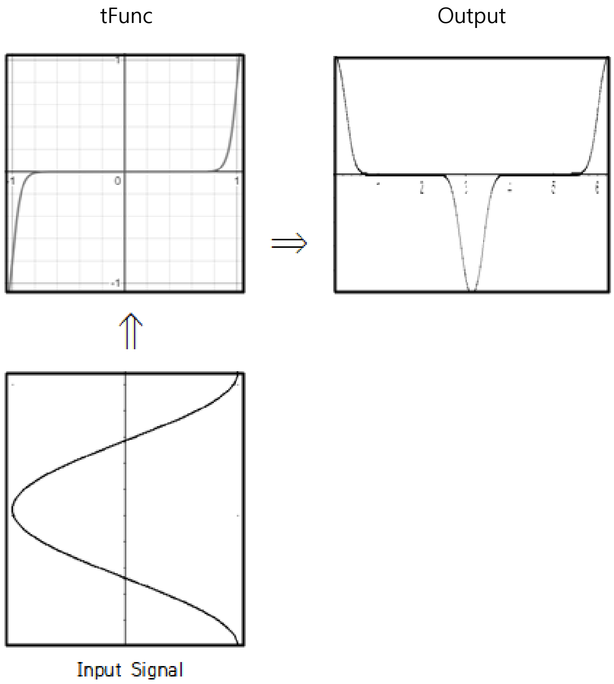
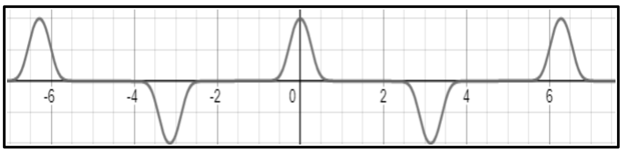


그림 18. $y=arctan((cosx)^{20})\bullet\frac{4}{\pi}$의 시간 영역에서의 그래프와 이를 얻어내는 과정(뒤에 붙은 4/π는 진폭을 1로 맞추기 위한 정규화를 위한 숫자이다)과 이를 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). DC성분이 관찰된다. 입력한 정현파의 주파수는 100Hz이다.

$y=arctan(x^{20})$와 같이 전달함수 속 변수 x를 짝수 거듭제곱을 했을 때는 그림 18에서처럼 전달함수 그래프의 개형이 일종의 납작한 "U"자 모양과 같이 형성되는데, 함숫값의 범위에 음수들이 포함되지 않는다(따라서 출력 신호에 DC성분이 포함되며 이는 단극성 신호가 되어버린다). 반면, $y=arctan(x^{21})$와 같이 전달함수 속 변수 x를 홀수 거듭제곱을 했을 때는 그래프의 개형이 짝수 거듭제곱일 때와는 다른 양상을 띤다.





```
(
{
var n = 17;
a = Signal.newClear((2**n) + 1);
b = Buffer.alloc(s, (2**(n+1)), 1, bufnum: 1);
a.waveFill({|x| x**21}, -1, 1);
b.loadCollection(a.asWavetableNoWrap);
b.plot;

Shaper.ar(
b, SinOsc.ar(100, 0, mul: 1), 1).atan*4/pi;
}.play;
)
```

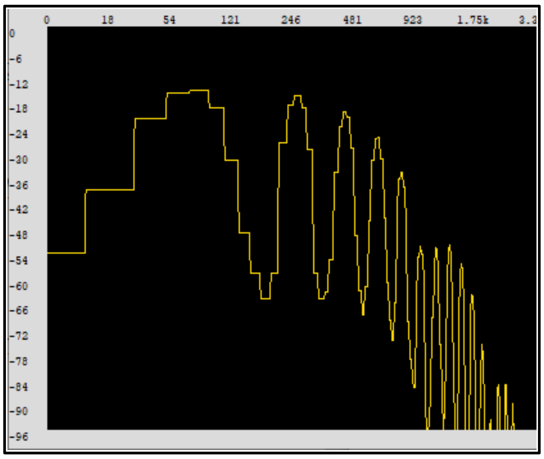
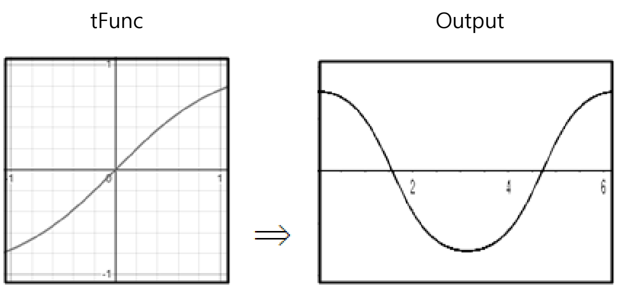


그림 19. $y=arctan(cos(x^{21}))\cdot\frac{4}{\pi}$ 의 시간 영역에서의 그래프와 이를 얻어내는 과정(뒤에 붙은 4/π는 진폭을 1로 맞추기 위한 정규화를 위한 숫자이다)과 이를 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). 앞선 경우와 다르게 DC성분이 관찰되지 않는다. 입력한 정현파의 주파수는 100Hz이다.

그림 19에서와 같이 아크탄젠트 전달함수 속의 변수 x를 홀수 거듭제곱하면, 전달함수 그래프의 개형이 양수와 음수 범위에 모두 걸쳐서 나타난다. 따라서 출력 신호는 양극성 신호가 되고 DC성분은 관찰되지 않으며, 그림 18에서의 경우에 비해 한 옥타브 낮은 소리가 만들어진다.

그림 18이나 19에서와 같은 전달함수 역시 유효한 결과를 얻기 위해 매우 많은 매클로린 급수의 항들이 필요하여 출력 신호에서의 주파수 성분들의 강도를 하나하나 알아내는 과정이 간단하지 않다.

[4] $y=tanhx$의 경우



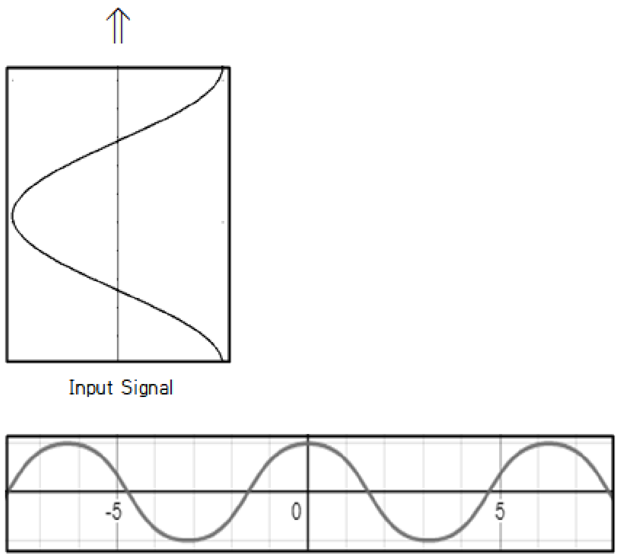


그림 20. $y=tanh(cosx)\bullet\frac{1000}{762}$의 시간 영역에서의 그래프와 이를 얻는 과정(뒤에 붙은 "*1000/762"는 출력 신호의 진폭을 1로 맞추기 위해 진행된 진폭의 정규화를 위한 숫자다).

쌍곡탄젠트 함수($y=tanhx$)를 매클로린 급수로 나타내고, 이를 통해 단위 정현파 입력의 파형성형의 결과를 계산하면 아래와 같다.

$$tanhx=\sum_{n=1}^{\infty}\frac{(16^n-4^n)B_{2n}x^{2n-1}}{(2n)!}=x-\frac{x^3}{3}+\frac{2}{15}x^5-\frac{17}{315}x^7+\dots$$

$$tanh(\cos x)=$$

$$\cos x-\frac{1}{3\bullet4}(3\cos x+\cos 3x)$$

$$+\frac{2}{15\bullet16}(10\cos x+5\cos 3x+\cos 5x)$$

$$-\frac{17}{315\bullet64}(35\cos x+21\cos 3x+7\cos 5x+\cos 7x)$$

$$+\dots$$

$$=0.8038194\cos x-0.0475694\cos 3x$$

$$+0.0024305\cos 5x-03000843\cos 7x$$

$$+\dots$$

식 18. 쌍곡탄젠트 함수를 매클로린 급수 형태로 표현한 것(B는 베르누이 수열이다)과 이를 이용한 단위 정현파 입력의 파형성형 계산 과정과 그 결과(단, 결과는 $y=tanhx$의 매클로린 급수의 네 번째 항까지만을 포함하여 계산한 근삿값이다).

그림 20에서 나타난 쌍곡탄젠트 전달함수의 개형은 아크탄젠트 함수와 매우 유사하다. 따라서 전술한 아크탄젠트 전달함수처럼 입력 신호인 정현파의 마루 부분을 골 방향으로 조금씩 찌그러트리는 작용을 하게 된다. 출력 신호 속에서는 사인함수일 때, 그리고 아크탄젠트 함수일 때와 마찬가지로 홀수 번째 배음들만이 관찰된다.

```
(
{
    SinOsc.ar(100, mul:1).tanh*(1000/762);
}.play;
)
```

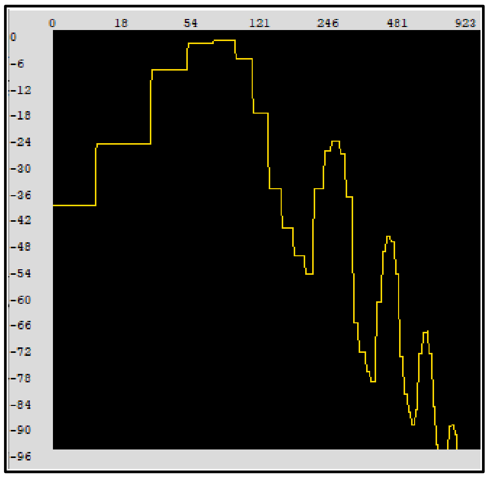
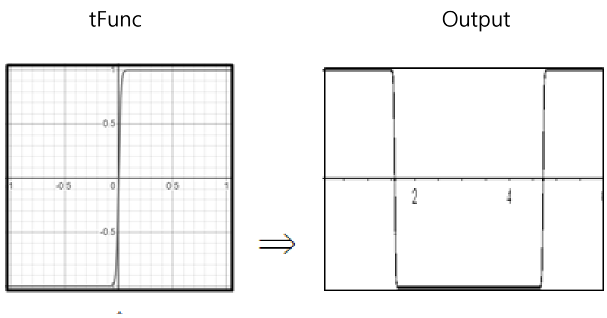
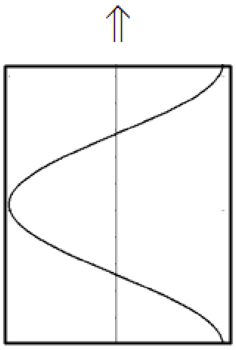
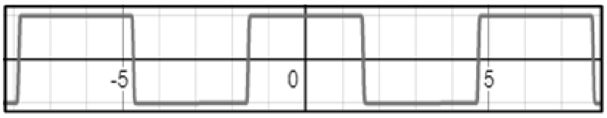


그림 21. 그림 20에서의 파형을 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale). 입력한 정현파의 주파수는 100Hz이다.

그리고 쌍곡탄젠트 전달함수의 변수 앞에 계수를 붙여 이용해도 아크탄젠트 함수에서의 경우처럼 더욱 많은 왜곡이 일어나게 유도할 수 있다. 아래에서는 식 $y=tanh(50\bullet cosx)$로 만들어 낼 수 있는 파형성형의 예시를 보이고 있다. 이 전달함수 역시 유효한 결과를 얻기 위한 계산 과정이 매우 복잡한 편이다.








```
(
{
	SinOsc.ar(100, mul:50).tanh;
}.play;
)
```

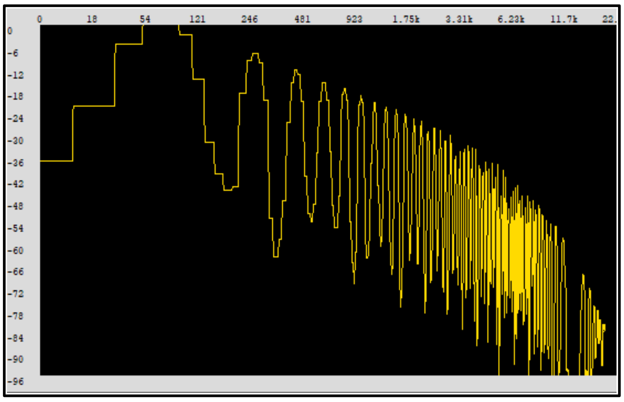


그림 22. $y=tanh50(cosx)$의 시간 영역에서의 그래프와 이를 얻는 과정과 이를 주파수 영역에서 관찰한 것(Logarithmic Frequency Scale).

[5] 비선형 전달함수들의 혼합

앞서 [1]~[4]까지는 삼각함수의 영역 안에서의 전달함수를 가지는 시스템을 통한 왜곡 합성의 결과에 대해 알아보았으나, 이외의 비선형 함수를 통해서도 얼마든지 흥미로운 왜곡의 결과를 만들 수 있다. 유리함수, 지수함수나 로그함수 등의 함수들도 얼마든지 x 축 상의 ±1 범위 속에서 함숫값을 만들어낼 수 있도록 만든다면 전달함수로 쓰일 수 있다. 간단한 예를 들어 본다면 $y=x/(a+b|x|)$ 와 같은 형태로 절댓값 기호를 포함한 유리함수는 앞서 언급한 $y=tanhx$와 비슷한 모양을 띠게 되어 입력 신호에 많은 고주파 성분을 추가적으로 발생시킬 수 있으며, 자연상수 e 를 밑(base)으로 가지는 지수함수를 토대로 구성된 유리함수 $y=\frac{be^{ax}}{e^{ax}+1}$의 꼴과 같은 전달함수 역시 $y=tanhx$와 유사한 그래프 개형으로 표현될 수 있으며, 따라서 많은 배음들을 만들어낼 수 있다. 아래에 언급한 두 가지 전달함수의 예시를 그래프 형태로 보인다.

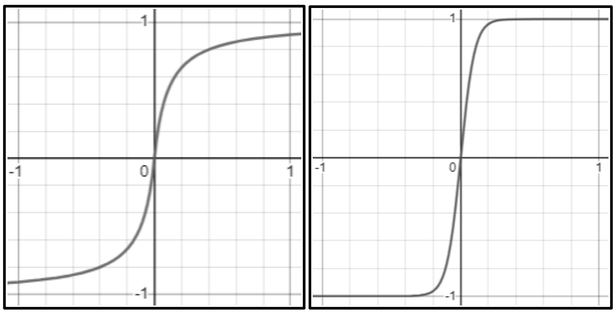


그림 23. 좌측 그래프는 $y=x/(a+b|x|)$형태의 그래프(a=0.1, b=1)이고, 우측 그래프는 $y=\frac{be^{ax}}{e^{ax}+1}$형태의 그래프(a=20, b=2)이다.

전술된 여러 가지 비선형 전달함수들 중 몇 가지를 혼합해 쓴다면 더 효과적으로 많은 부분음들을 만들어낼 수 있을 것이다. 임의로 만든 한 전달함수의 예를 들어 단순 정현파 입력 신호를 이용한 파형성형을 한 후, 출력 신호의 성분들까지 해석하는 사례 한 가지를 구성해 보았다. 임의로 구성해 본 전달함수는 아래와 같다. 이는 지수함수와 삼각함수와 다항함수가 모두 이용된 형태이다.

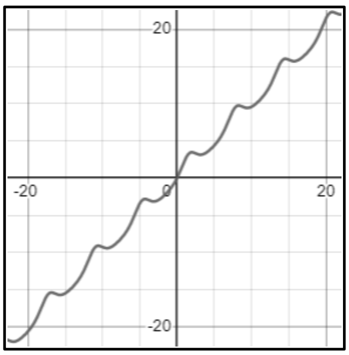


그림 24. 전달함수로 이용될 함수 "$y=e^{sinx}+x-1$" 그래프의 개형.

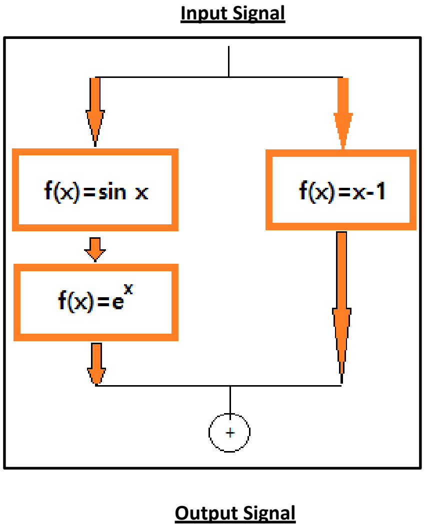


그림 25. 전달함수 $f(x)=e^{sinx}+x-1$가 적용되는 전반적 과정을 그린 블록선도.

그림 24에 나타난 함수 "$y=e^{sinx}+x-1$"을 매클로린 급수의 형태로 표현해야 이 함수를 전달함수로 가지는 시스템을 해석할 수 있는데 이 함수 속의 비선형 함수인 항은 첫 항인 e^{sinx}뿐이므로, 이 항만을 매클로린 급수의 형태로 풀어내면 된다. e^{sinx}항을 매클로린 급수의 형태로 전개하여 나타내면 아래와 같다.

$$e^{sinx}= 1+x+\frac{x^2}{2}+\frac{x^4}{8}-\frac{x^5}{15}-\frac{x^6}{240}+\frac{x^7}{90}+\frac{31x^8}{5760}+\frac{x^9}{5670}+...$$

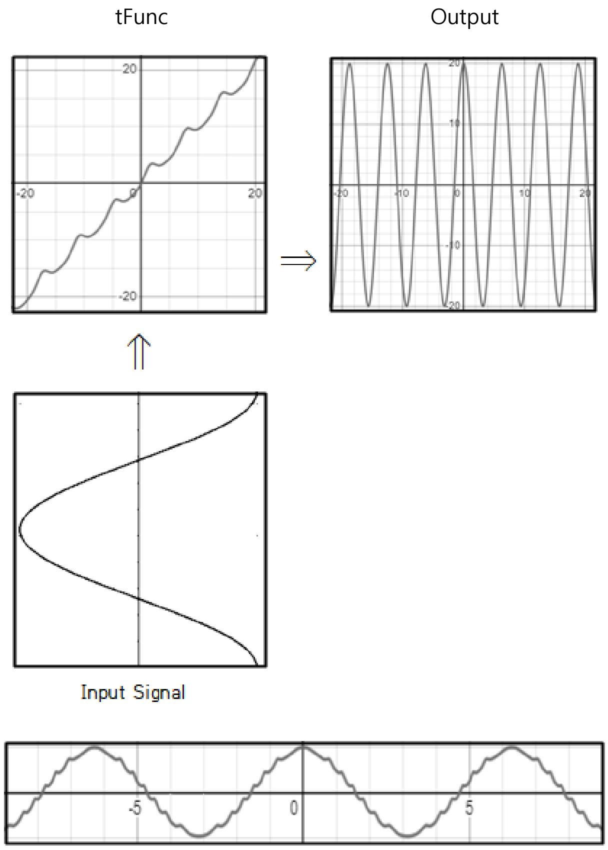
식 19. $y=e^{sinx}$를 매클로린 급수의 형태로 표현한 식. x의 세제곱 항이 제외되어 있는 것이 특기할 만한 점이다.

식 19에 나머지 항인 "x-1"이 더해지면 아래와 같다.

$$e^{sinx}+x-1= 2x+\frac{x^2}{2}+\frac{x^4}{8}-\frac{x^5}{15}-\frac{x^6}{240}+\frac{x^7}{90}+\frac{31x^8}{5760}+\frac{x^9}{5670}+...$$

식 20. $y=e^{sinx}+x-1$를 매클로린 급수의 형태로 표현한 식.

그림 24 에서 보이듯, 이 전달함수는 x, y 축 상 ±1 의 범위 안에서는 상대적으로 굴곡이 크지 않아서, 입력 신호인 단순 정현파의 진폭을 20 배(임의의 수치이다)와 같이 크게 증폭하여 시스템에 부여하면 더 많은 왜곡을 만들어 낼 수 있다. 이 파형성형의 결과는 식 20 속의 변수 x 의 자리에 $20cos\,x$를 대입하여 표현할 수 있다. 그렇게 되면 식 20 의 매클로린 급수를 구성하는 각각의 항들은 계수가 제각각인 정현파의 N-제곱의 합으로 표현될 수 있으며, 이는 앞서 언급한 식 1 을 통해 단순 정현파들의 합의 형태로까지 풀어서 파형성형 결과의 주파수 성분들을 낱낱이 알 수 있다. 참고로 파형성형의 식인 "$y=e^{sin(20cos\,x)}+20cosx-1$"의 계산 결과로 얻을 수 있는 함수의 진폭은 21.492 가 되어버린다. 따라서, 계산 결과를 21.492 라는 숫자로 나누어 정규화해야 한다.




```
(
{
    var e, sig;

    e=exp(1);
    sig=
(e**SinOsc.ar(100, mul:20).sin)
+ SinOsc.ar(100, mul: 20)-1;
    sig/21.492;
}.play;
)
```

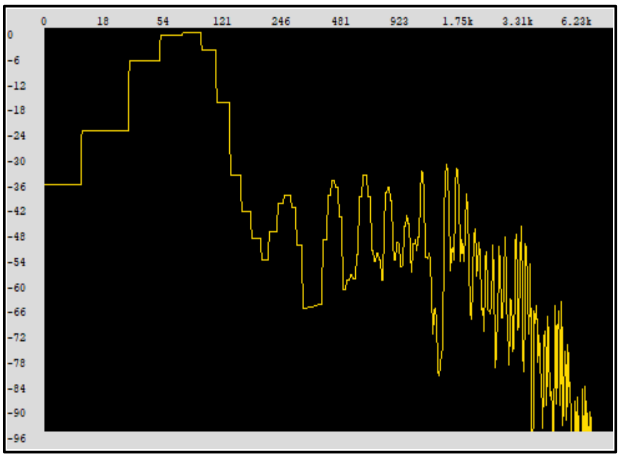


그림 26. "$y=(e^{sin(20cos x)}+20cosx-1)/21.492$"의 형태로 파형성형하여 얻은 출력 신호를 시간 영역과 주파수 영역에서 각각 나타낸 것(Logarithmic Frequency Scale).

그림 26 의 스펙트럼을 보면 명확한 경향성이 직관적으로 보이지 않는다. 그 이유들은 계수들의 값의 편차가 항마다 심하다는 것과, 식 20 에서 알 수 있듯이 매클로린 급수 표현에서 세제곱의 항이 제외되어 있어서일 것으로 추론해 볼 수 있다. 그리고 $y=e^{sinx}+x-1$이라는 전달함수 그래프 상에서의 여러 굴곡의 무리를 조금이라도 비슷하게 표현하기 위해서는 적어도 수십 개 정도의 상당히 많은 테일러 급수의 항이 필요하므로, 파형성형 결과에서 생기는 각각의 주파수 성분들의 강도값들을 하나하나 알아내는 과정이 복잡하다.

결론과 추가 연구의 방향

비선형 전달함수를 가지는 많은 시스템에서의 출력 신호 특성을 예측하기란 전달함수가 선형인 경우에 비해 비교적 어렵다. 하지만 비교적 연구 결과가 많이 축적된 "N-제곱 형태의 전달함수를 가지는 시스템에 입력 신호로 진폭이 1인 단위 정현파를 부여하는 경우"의 사례를 바탕으로 입력 정현파 신호의 진폭이 1이 아닌 경우와 입력 신호가 복합음일 경우의 출력 신호를 분석하는 방법을 소개했으며, 특히 입력 신호가 협화적 복합음일 경우에 출력 신호 속 주파수 성분들의 강도값 사이의 규칙들을 일부 찾아냈다.

그 후, 비선형 전달함수를 다항함수의 N-제곱 항의 선형합으로 나타내는 테일러 급수, 그 중에서도 해석이 비교적 용이한 매클로린 급수와 더불어 많은 비선형 함수들 가운데 다양한 삼각함수들을 매클로린 급수의 형태로 전개하여 표현하는 방법을 알아보았고, 그들을 전달함수로 이용하여 만들어낸 파형성형의 결과를 확인해보았다. 그리고 여러 비선형 함수를 혼합한 형태의 전달함수를 이용하는 파형성형의 결과를 해석하는 방법에 대해서도 간략한 사례를 통해 소개하였다.

추가 연구의 방향으로는 많은 비선형 함수들의 혼합을 통해 만들어낼 수 있는 다양한 왜곡 합성법의 사례들을 찾아내는 것이 있을 것이다. 특히, 전달함수의 ±1 범위 속에서 영역을 나누어 각 영역마다 다른 함수들을 배치하여 전달함수로 이용하는 경우도 있을 것이다. 이런 방법 하에서는 출력 신호의 시간 영역에서의 파형이 비대칭 형태가 될 수도 있으며 주파수 영역에서의 다양한 지점들에서 더 많은 부분음들을 만들기 용이해지지만, 그 경향성의 예측은 더욱 어려워진다. 왜곡 합성(Distortion Synth)이라는 범주 안에서 합성된 소리의 다양한 질감 창출을 위하여 다양한 형태의 비선형 전달함수와 그들의 혼합태(직렬 혹은 병렬 조합)는 아직 더 많은 연구가 필요한 것으로 보인다.

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Generating sounds by using Simplex noise algorithm

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Ken Perlin developed new noise algorithm called *Perlin noise* in 1985, then he upgraded that to more sophisticated algorithm which is called *Simplex noise* in 2001. Simplex noise has been often used in the field of computer graphics. As opposed to simple random value, it can be used for generating very smooth random values. We can use this characteristics for manipulating a variety of parameters of sounds. We first used those values for dynamic changes of Frequency Bin's values of 24 simple oscillators (each oscillator has 512 Frequency Bins) and also for dynamic pitch-shifts of those oscillators. This system took then 512 × 24 + 512 × 1 elements, but kept high speed operation by virtue of simplicity of Simplex noise algorithm. As a result, we can get very interesting and complex sounds with a few simple steps. In addition, we can construct very complex interactive system between Max/Msp and Unity. This results in an extension of music to visual expression in same Simplex noise algorithm. We found that Simplex noise is new useful way and has vast possibilities for computer music.

Keywords: Computer music composition, Algorithmic composition, Simplex noise, Interactive expression.

Ken Perlin developed new noise algorithm called *Perlin noise* in 1985, then he upgraded that to more sophisticated algorithm which is called *Simplex noise* in 2001. Simplex noise has been often used in the field of computer graphics. As opposed to simple random value, it can be used for generating very smooth random values.

Perlin Noise and Simplex Noise

Now we are going to take a quick look at both Perlin noise and Simplex noise algorithm. Perlin first developed the noise algorithm which has been called *gradient noise* or *classic Perlin noise* in 1985. The most remarkable feature of this noise is that it generates very smooth continuous random values unlike simple randomness. Stefan Gustavson describes brilliantly the character of this noise:

> Perlin noise is a so-called gradient noise, which means that you set a pseudo-random gradient at regularly spaced points in space, and interpolate a smooth function between those points. (Gustavson 2005: 1)

However, according to Perlin, this algorithm has following shortcomings that would be of particular consequence in a real-time setting and in a hardware implementation:

1. Lack of a single standard reference implementation
2. Requiring many multiplies
3. Visually significant anisotropy
4. Gradient artifacts
5. Difficulty of computing a derivative
6. Need for table memory
7. Memory-limited extent of the volume tile
8. Expense of generalizing to higher dimensions
9. Lack of separation between signal and reconstruction (Perlin 2001: 2)

Since this paper is not about technical detail of Perlin noise, we don't get involved in that. Instead of classic Perlin noise algorithm, Perlin developed a new noise algorithm which is called *Simplex noise*. To generate that, he give just following three steps:

1. Given an input point
2. For each of its neighboring grid points:
- Pick a "pseudo-random" direction vector
- Compute linear function (dot product)
3. Linearly combine with a weighted sum, using a cubic ease curve in each dimension, such as 3t^2-2t^3, as the interpolant. (Perlin 2001: 3)

Then,

In three dimensions, there are eight surrounding grid points. To combine their respective influences we use a trilinear interpolation (linear interpolation in each of three dimensions).

> In practice this means that once we've computed the 3t^2-2t^3 cross-fade function in each of x,y and z, respectively, then we'll need to do seven linear interpolations to get the final result. (Perlin 2001: 4)

Finally we get following figure as an example from Gustavson:

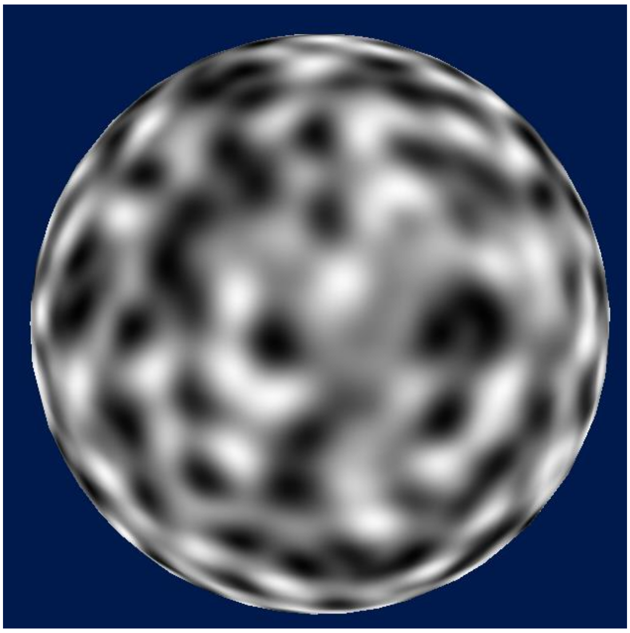


Figure 1. 3D Simplex noise.

Practices of Simplex Noise

Code and its economy

The actual code which Gustavson wrote is very comprex. Let us take a 4D Simplex noise example in Java:

```java
public class SimplexNoise {  // Simplex noise in 2D, 3D and 4D

  private static int grad3[][] = {{1,1,0},{-1,1,0},{1,-1,0},{-1,-1,0},
                                  {1,0,1},{-1,0,1},{1,0,-1},{-1,0,-1},
                                  {0,1,1},{0,-1,1},{0,1,-1},{0,-1,-1}};

  private static int grad4[][]= {{0,1,1,1}, {0,1,1,-1}, {0,1,-1,1}, {0,1,-1,-1},
                   {0,-1,1,1}, {0,-1,1,-1}, {0,-1,-1,1}, {0,-1,-1,-1},
                   {1,0,1,1}, {1,0,1,-1}, {1,0,-1,1}, {1,0,-1,-1},
                   {-1,0,1,1}, {-1,0,1,-1}, {-1,0,-1,1}, {-1,0,-1,-1},
                   {1,1,0,1}, {1,1,0,-1}, {1,-1,0,1}, {1,-1,0,-1},
                   {-1,1,0,1}, {-1,1,0,-1}, {-1,-1,0,1}, {-1,-1,0,-1},
                   {1,1,1,0}, {1,1,-1,0}, {1,-1,1,0}, {1,-1,-1,0},
                   {-1,1,1,0}, {-1,1,-1,0}, {-1,-1,1,0}, {-1,-1,-1,0}};

  private static int p[] = {151,160,137,91,90,15,
  131,13,201,95,96,53,194,233,7,225,140,36,103,30,69,142,8,99,37,240,21,10,23,
  190, 6,148,247,120,234,75,0,26,197,62,94,252,219,203,117,35,11,32,57,177,33,
  88,237,149,56,87,174,20,125,136,171,168, 68,175,74,165,71,134,139,48,27,166,
  77,146,158,231,83,111,229,122,60,211,133,230,220,105,92,41,55,46,245,40,244,
  102,143,54, 65,25,63,161, 1,216,80,73,209,76,132,187,208, 89,18,169,200,196,
  135,130,116,188,159,86,164,100,109,198,173,186, 3,64,52,217,226,250,124,123,
  5,202,38,147,118,126,255,82,85,212,207,206,59,227,47,16,58,17,182,189,28,42,
  223,183,170,213,119,248,152, 2,44,154,163, 70,221,153,101,155,167, 43,172,9,
  129,22,39,253, 19,98,108,110,79,113,224,232,178,185, 112,104,218,246,97,228,
  251,34,242,193,238,210,144,12,191,179,162,241, 81,51,145,235,249,14,239,107,
  49,192,214, 31,181,199,106,157,184, 84,204,176,115,121,50,45,127, 4,150,254,
  138,236,205,93,222,114,67,29,24,72,243,141,128,195,78,66,215,61,156,180};

  // To remove the need for index wrapping, double the permutation table length
  private static int perm[] = new int[512];
  static { for(int i=0; i<512; i++) perm[i]=p[i & 255]; }

  // A lookup table to traverse the simplex around a given point in 4D.
  // Details can be found where this table is used, in the 4D noise method.
  private static int simplex[][] = {
    {0,1,2,3},{0,1,3,2},{0,0,0,0},{0,2,3,1},{0,0,0,0},{0,0,0,0},{0,0,0,0},{1,2,3,0},
    {0,2,1,3},{0,0,0,0},{0,3,1,2},{0,3,2,1},{0,0,0,0},{0,0,0,0},{0,0,0,0},{1,3,2,0},
    {0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},
    {1,2,0,3},{0,0,0,0},{1,3,0,2},{0,0,0,0},{0,0,0,0},{0,0,0,0},{2,3,0,1},{2,3,1,0},
    {1,0,2,3},{1,0,3,2},{0,0,0,0},{0,0,0,0},{0,0,0,0},{2,0,3,1},{0,0,0,0},{2,1,3,0},
    {0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},{0,0,0,0},
    {2,0,1,3},{0,0,0,0},{0,0,0,0},{0,0,0,0},{3,0,1,2},{3,0,2,1},{0,0,0,0},{3,1,2,0},
    {2,1,0,3},{0,0,0,0},{0,0,0,0},{0,0,0,0},{3,1,0,2},{0,0,0,0},{3,2,0,1},{3,2,1,0}};

  // This method is a *lot* faster than using (int)Math.floor(x)
  private static int fastfloor(double x) {
    return x>0 ? (int)x : (int)x-1;
  }

  private static double dot(int g[], double x, double y) {
    return g[0]*x + g[1]*y; }

  private static double dot(int g[], double x, double y, double z) {
    return g[0]*x + g[1]*y + g[2]*z; }

  private static double dot(int g[], double x, double y, double z, double w) {
    return g[0]*x + g[1]*y + g[2]*z + g[3]*w; }
```

```java
// 4D simplex noise
double noise(double x, double y, double z, double w) {

  // The skewing and unskewing factors are hairy again for the 4D case
  final double F4 = (Math.sqrt(5.0)-1.0)/4.0;
  final double G4 = (5.0-Math.sqrt(5.0))/20.0;
  double n0, n1, n2, n3, n4; // Noise contributions from the five corners

  // Skew the (x,y,z,w) space to determine which cell of 24 simplices we're in
  double s = (x + y + z + w) * F4; // Factor for 4D skewing
  int i = fastfloor(x + s);
  int j = fastfloor(y + s);
  int k = fastfloor(z + s);
  int l = fastfloor(w + s);

  double t = (i + j + k + l) * G4; // Factor for 4D unskewing
  double X0 = i - t; // Unskew the cell origin back to (x,y,z,w) space
  double Y0 = j - t;
  double Z0 = k - t;
  double W0 = l - t;

  double x0 = x - X0;  // The x,y,z,w distances from the cell origin
  double y0 = y - Y0;
  double z0 = z - Z0;
  double w0 = w - W0;

  // For the 4D case, the simplex is a 4D shape I won't even try to describe.
  // To find out which of the 24 possible simplices we're in, we need to
  // determine the magnitude ordering of x0, y0, z0 and w0.
  // The method below is a good way of finding the ordering of x,y,z,w and
  // then find the correct traversal order for the simplex we're in.
  // First, six pair-wise comparisons are performed between each possible pair
  // of the four coordinates, and the results are used to add up binary bits
  // for an integer index.
  int c1 = (x0 > y0) ? 32 : 0;
  int c2 = (x0 > z0) ? 16 : 0;
  int c3 = (y0 > z0) ? 8 : 0;
  int c4 = (x0 > w0) ? 4 : 0;
  int c5 = (y0 > w0) ? 2 : 0;
  int c6 = (z0 > w0) ? 1 : 0;
  int c = c1 + c2 + c3 + c4 + c5 + c6;

  int i1, j1, k1, l1; // The integer offsets for the second simplex corner
  int i2, j2, k2, l2; // The integer offsets for the third simplex corner
  int i3, j3, k3, l3; // The integer offsets for the fourth simplex corner

  // simplex[c] is a 4-vector with the numbers 0, 1, 2 and 3 in some order.
  // Many values of c will never occur, since e.g. x>y>z>w makes x<z, y<w and x<w
  // impossible. Only the 24 indices which have non-zero entries make any sense.
  // We use a thresholding to set the coordinates in turn from the largest magnitude.
  // The number 3 in the "simplex" array is at the position of the largest coordinate.
  i1 = simplex[c][0]>=3 ? 1 : 0;
  j1 = simplex[c][1]>=3 ? 1 : 0;
  k1 = simplex[c][2]>=3 ? 1 : 0;
  l1 = simplex[c][3]>=3 ? 1 : 0;
  // The number 2 in the "simplex" array is at the second largest coordinate.
  i2 = simplex[c][0]>=2 ? 1 : 0;
  j2 = simplex[c][1]>=2 ? 1 : 0;

  k2 = simplex[c][2]>=2 ? 1 : 0;
  l2 = simplex[c][3]>=2 ? 1 : 0;
  // The number 1 in the "simplex" array is at the second smallest coordinate.
  i3 = simplex[c][0]>=1 ? 1 : 0;
  j3 = simplex[c][1]>=1 ? 1 : 0;
  k3 = simplex[c][2]>=1 ? 1 : 0;
  l3 = simplex[c][3]>=1 ? 1 : 0;
  // The fifth corner has all coordinate offsets = 1, so no need to look that up.

  double x1 = x0 - i1 + G4; // Offsets for second corner in (x,y,z,w) coords
  double y1 = y0 - j1 + G4;
  double z1 = z0 - k1 + G4;
  double w1 = w0 - l1 + G4;
  double x2 = x0 - i2 + 2.0*G4; // Offsets for third corner in (x,y,z,w) coords
  double y2 = y0 - j2 + 2.0*G4;
  double z2 = z0 - k2 + 2.0*G4;
  double w2 = w0 - l2 + 2.0*G4;
  double x3 = x0 - i3 + 3.0*G4; // Offsets for fourth corner in (x,y,z,w) coords
  double y3 = y0 - j3 + 3.0*G4;
  double z3 = z0 - k3 + 3.0*G4;
  double w3 = w0 - l3 + 3.0*G4;
  double x4 = x0 - 1.0 + 4.0*G4; // Offsets for last corner in (x,y,z,w) coords
  double y4 = y0 - 1.0 + 4.0*G4;
  double z4 = z0 - 1.0 + 4.0*G4;
  double w4 = w0 - 1.0 + 4.0*G4;

  // Work out the hashed gradient indices of the five simplex corners
  int ii = i & 255;
  int jj = j & 255;
  int kk = k & 255;
  int ll = l & 255;
  int gi0 = perm[ii+perm[jj+perm[kk+perm[ll]]]] % 32;
  int gi1 = perm[ii+i1+perm[jj+j1+perm[kk+k1+perm[ll+l1]]]] % 32;
  int gi2 = perm[ii+i2+perm[jj+j2+perm[kk+k2+perm[ll+l2]]]] % 32;
  int gi3 = perm[ii+i3+perm[jj+j3+perm[kk+k3+perm[ll+l3]]]] % 32;
  int gi4 = perm[ii+1+perm[jj+1+perm[kk+1+perm[ll+1]]]] % 32;

  // Calculate the contribution from the five corners
  double t0 = 0.6 - x0*x0 - y0*y0 - z0*z0 - w0*w0;
  if(t0<0) n0 = 0.0;
  else {
    t0 *= t0;
    n0 = t0 * t0 * dot(grad4[gi0], x0, y0, z0, w0);
  }

  double t1 = 0.6 - x1*x1 - y1*y1 - z1*z1 - w1*w1;
  if(t1<0) n1 = 0.0;
  else {
    t1 *= t1;
    n1 = t1 * t1 * dot(grad4[gi1], x1, y1, z1, w1);
  }

  double t2 = 0.6 - x2*x2 - y2*y2 - z2*z2 - w2*w2;
  if(t2<0) n2 = 0.0;
  else {
    t2 *= t2;
    n2 = t2 * t2 * dot(grad4[gi2], x2, y2, z2, w2);
  }

  double t3 = 0.6 - x3*x3 - y3*y3 - z3*z3 - w3*w3;
  if(t3<0) n3 = 0.0;
  else {
    t3 *= t3;
    n3 = t3 * t3 * dot(grad4[gi3], x3, y3, z3, w3);
  }

  double t4 = 0.6 - x4*x4 - y4*y4 - z4*z4 - w4*w4;
  if(t4<0) n4 = 0.0;
  else {
    t4 *= t4;
    n4 = t4 * t4 * dot(grad4[gi4], x4, y4, z4, w4);
  }

  // Sum up and scale the result to cover the range [-1,1]
  return 27.0 * (n0 + n1 + n2 + n3 + n4);
  }
}
```

Figure 2. Code of 4D Simplex noise by Gustavson

As Gustavson wrote, this code is unnecessarily long-winded due to our readability. The next one is written in WebGL by McEwan:

```
vec3 mod289(vec3 x) {
  return x - floor(x * (1.0 / 289.0)) * 289.0;
}

vec4 mod289(vec4 x) {
  return x - floor(x * (1.0 / 289.0)) * 289.0;
}

vec4 permute(vec4 x) {
     return mod289(((x*34.0)+10.0)*x);
}

vec4 taylorInvSqrt(vec4 r)
{
  return 1.79284291400159 - 0.85373472095314 * r;
}

float snoise(vec3 v)
  {
  const vec2  C = vec2(1.0/6.0, 1.0/3.0) ;
  const vec4  D = vec4(0.0, 0.5, 1.0, 2.0);

// First corner
  vec3 i  = floor(v + dot(v, C.yyy) );
  vec3 x0 =   v - i + dot(i, C.xxx) ;

// Other corners
  vec3 g = step(x0.yzx, x0.xyz);
  vec3 l = 1.0 - g;
  vec3 i1 = min( g.xyz, l.zxy );
  vec3 i2 = max( g.xyz, l.zxy );

  //   x0 = x0 - 0.0 + 0.0 * C.xxx;
  //   x1 = x0 - i1  + 1.0 * C.xxx;
  //   x2 = x0 - i2  + 2.0 * C.xxx;
  //   x3 = x0 - 1.0 + 3.0 * C.xxx;
  vec3 x1 = x0 - i1 + C.xxx;
  vec3 x2 = x0 - i2 + C.yyy; // 2.0*C.x = 1/3 = C.y
  vec3 x3 = x0 - D.yyy;      // -1.0+3.0*C.x = -0.5 = -D.y

// Permutations
  i = mod289(i);
  vec4 p = permute( permute( permute(
             i.z + vec4(0.0, i1.z, i2.z, 1.0 ))
           + i.y + vec4(0.0, i1.y, i2.y, 1.0 ))
           + i.x + vec4(0.0, i1.x, i2.x, 1.0 ));

// Gradients: 7x7 points over a square, mapped onto an octahedron.
// The ring size 17*17 = 289 is close to a multiple of 49 (49*6 = 294)
  float n_ = 0.142857142857; // 1.0/7.0
  vec3  ns = n_ * D.wyz - D.xzx;

  vec4 j = p - 49.0 * floor(p * ns.z * ns.z);  //  mod(p,7*7)

  vec4 x_ = floor(j * ns.z);
  vec4 y_ = floor(j - 7.0 * x_ );    // mod(j,N)

  vec4 x = x_ *ns.x + ns.yyyy;
  vec4 y = y_ *ns.x + ns.yyyy;
  vec4 h = 1.0 - abs(x) - abs(y);

  vec4 b0 = vec4( x.xy, y.xy );
  vec4 b1 = vec4( x.zw, y.zw );

  //vec4 s0 = vec4(lessThan(b0,0.0))*2.0 - 1.0;
  //vec4 s1 = vec4(lessThan(b1,0.0))*2.0 - 1.0;
  vec4 s0 = floor(b0)*2.0 + 1.0;
  vec4 s1 = floor(b1)*2.0 + 1.0;
  vec4 sh = -step(h, vec4(0.0));

  vec4 a0 = b0.xzyw + s0.xzyw*sh.xxyy ;
  vec4 a1 = b1.xzyw + s1.xzyw*sh.zzww ;

  vec3 p0 = vec3(a0.xy,h.x);
  vec3 p1 = vec3(a0.zw,h.y);
  vec3 p2 = vec3(a1.xy,h.z);
  vec3 p3 = vec3(a1.zw,h.w);

//Normalise gradients
  vec4 norm = taylorInvSqrt(vec4(dot(p0,p0), dot(p1,p1), dot(p2, p2), dot(p3,p3)));
  p0 *= norm.x;
  p1 *= norm.y;
  p2 *= norm.z;
  p3 *= norm.w;

// Mix final noise value
  vec4 m = max(0.5 - vec4(dot(x0,x0), dot(x1,x1), dot(x2,x2), dot(x3,x3)), 0.0);
  m = m * m;
  return 105.0 * dot( m*m, vec4( dot(p0,x0), dot(p1,x1),
                                dot(p2,x2), dot(p3,x3) ) );
  }
```

Figure 3. Code of 3D simplex noise by Ian McEwan, Ashima Arts.

If we want then a value from this simplex noise function, we can just write like this:

float value = snoise(vec3(a, b, c))

As we can see, once we define simplex noise, we can use that just as built-in function. As a result, we can use this algorithm easier than before at code-level.

Simplex Noise in Max/Msp

Now we are going to take simplex noise in Max/Msp, that is to say, in sounds. We can get that easily putting *jit.bfg object* and its attribute *@basis noise.simplex*.

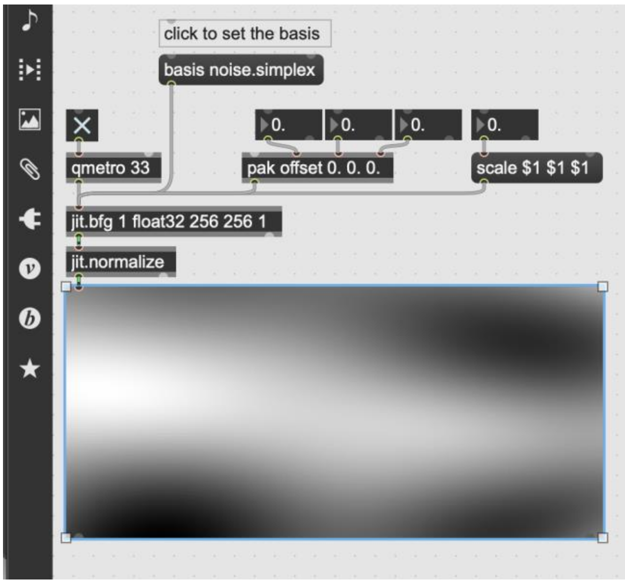


Figure 4. jit.bfg object and its attribute basis noise.simplex.in Max/Msp.

This object can has many parameters, but main ones are the *offset*, which changes the shape of noise smoothly, and the *scale*, which changes the scale of noise. Manipulating these parameters, we can control most of this object.

Then, how can we make sounds reflect simplex noise? One way we would like to take is to apply that to *Frequency Bin*'s values of some simple oscillators. Each pixel has 0.0 – 1.0 value, so if we take 24 simple oscillators and if each oscillator has 512 frequency bins, it is appropriate to regard this noise as a *matrix* which has 512 × 24 elements. To realize this idea, we wrote a code which stores each value in each buffer in JavaScript. In this code, we use *for loops* to write 512 real time values into frequency bins of each buffer:

```
function list(l){
    switch(this.inlet){
        case 0:
            indicies0 = arguments;
            for(var i = 0; i < 512; i++)
            {
                buf0.poke(1, i, (indicies0[i] - 0.5) * 1.7);
        //post(indicies0[i]);
            }
            break;
        case 1:
            indicies1 = arguments;
            for(var i = 0; i < 512; i++)
            {
                buf1.poke(1, i, (indicies1[i] - 0.5) * 1.7);
```

Figure 5. Storing values of simplex noise in buffers

As each value always changes in real time due to manipulation of parameters, the consequential sounds should also change in real time. However, we will use another simplex noise to change each pitch in order to exaggerate the final output. The final patch will be following:

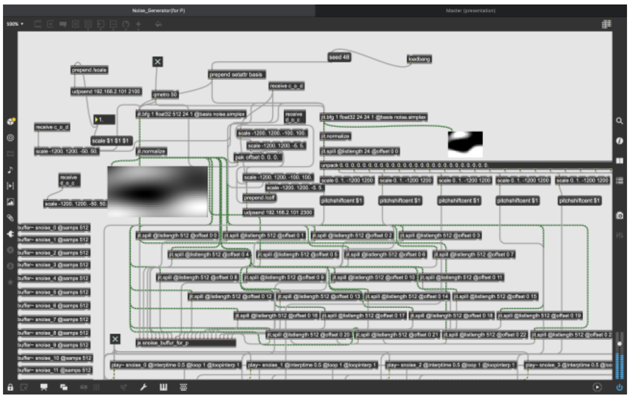


Figure 6. The final patch.

Extending Simplex Noise Sounds to Interactive Expression with Unity

Finally, we will present an extended version which makes sounds and visuals interact. We will use *Unity,* a game engine, for this purpose via OSC (Open Sound System) signals.

In Unity, we can use simplex noise in two ways. On the one hand, we write the code again in HLSL:

```
Assets > Shader > GPUTrailParticles.compute
float3 snoise3D(float4 x)
{
    float s = snoise(x);
    float s1 = snoise(float4(x.y - 19.1, x.z + 33.4, x.x + 47.2, x.w));
    float s2 = snoise(float4(x.z + 74.2, x.x - 124.5, x.y + 99.4, x.w));
    float3 c = float3(s, s1, s2);
    return c;
}

float3 curlNoise(float4 p) {

    const float e = 0.0009765625;
    float4 dx = float4(e, 0.0, 0.0, 0.0);
    float4 dy = float4(0.0, e, 0.0, 0.0);
    float4 dz = float4(0.0, 0.0, e, 0.0);

    float3 p_x0 = snoise3D(p - dx);
    float3 p_x1 = snoise3D(p + dx);
    float3 p_y0 = snoise3D(p - dy);
    float3 p_y1 = snoise3D(p + dy);
    float3 p_z0 = snoise3D(p - dz);
    float3 p_z1 = snoise3D(p + dz);

    float x = p_y1.z - p_y0.z - p_z1.y + p_z0.y;
    float y = p_z1.x - p_z0.x - p_x1.z + p_x0.z;
    float z = p_x1.y - p_x0.y - p_y1.x + p_y0.x;

    const float divisor = 1.0 / (2.0 * e);
    return normalize(float3(x, y, z) * divisor);
}
```

Figure 7. Code of simplex noise in HLSL.

This code is very similar to that of WebGL, so once we define the function, we can call it like built-in function.

On the other hand, we use *Shader Graph,* a system of Unity, with which we can treat shaders like graphical program language:

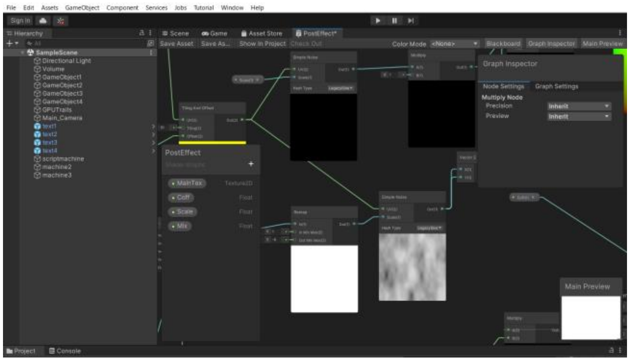
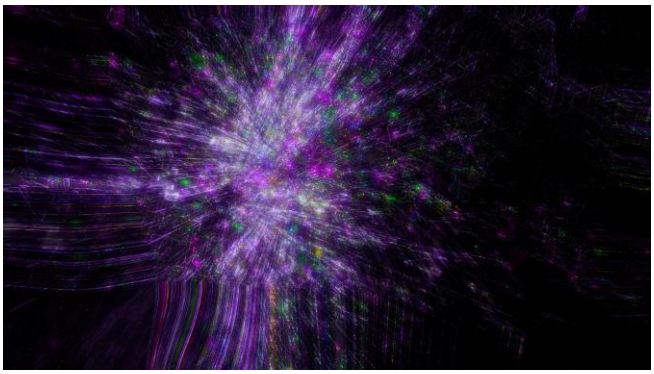


Figure 8. Simplex noise in Shader Graph.

Here is the example of interaction between Max/Msp and Unity, namely between sounds and visuals, using simplex noise:



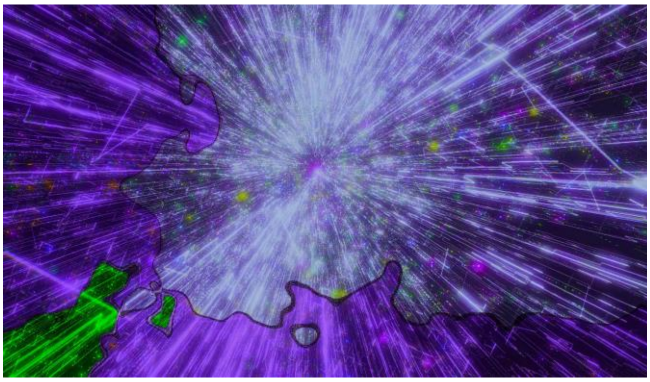


Figure 9. An example of interaction between Max/Msp and Unity from the piece *Psychedelic Circuit,* by Masafumi Oda.

Conclusion

We are seeing how useful and what a powerful way the simplex noise algorithm is, in both sounds and visuals. Since it generates very smooth random values in very easy way, it can be used to generate new sounds unlike using traditional frat randomness.

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Approaching to immersive sound perception through the ekphrasis

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The article explains an experiment that consisted of proposing an introspective reflection of immersive sound perception through the ekphrasis. In the execution, participants had an installation of 6 speakers that reproduced an acousmatic composition in continuous repetition. The methodology for the analysis was qualitative to produce representative data with the participation of 400 people divided in two groups; 200 responded individually a controlled survey for ekphrasis with 6 concepts: 10.08% related their listening to relaxation, 9.22% meditation, 9.04% depth, 9.04% tranquillity, 8.27% peace and 8.1% immersion. The other 200 responded without restraints where 7.6% wrote tranquillity, 5.9% peace and 4.4% relaxation, as the most important concepts. Both groups expressed coincidences through the concepts of tranquillity, relaxation and peace. Finally, by simple random selection a significant number of ekphrasis were chosen to expose the effects in sound perception.

Keywords: perception, hearing, immersion, acousmatic, ekphrasis.

Immersion is an effect without physical matter that can be perceived by the humans through their senses or the intellect. It has a universal and sociocultural character that has been historically transmitted between different cultures. Consequently, it is a phenomenon that concerns our perceptions, and its effects and interpretations define its intensity and actions.

Likewise, immersion experience produces delimited or imaginary spaces that allow us to confront ourselves with the mechanisms that produce it. Therefore, immersion forces us to base our perception through empirical analysis.

An immersive experience can change our perception approach to achieve significant orientation changes, as well as to calm or exalt the body.

The first step to create an immersive experience is the creation of perceptive space with their own narrative that can have different interactions. The matter of a possible case study is to understand the perception of immersive sound, more than the experience. The objective could be to understand the confrontation of our senses against the artifacts that produce the immersive effect. As a result, it would be possible to base other forms of perception.

An experiment consisted in researching the introspective reflection through the ekphrasis produced by the immersive sound. The experiment had a sound installation (6 speakers) within an area of about 310 m^2. The immersive sound was produced at 51.4dB with an acousmatic composition in continuous repetition (5 hours per day for 3 weeks).

Methodological representative approaches in compilation and analysis of statistical and qualitative data on ekphrasis were designed.

The experiment had 400 participants that were divided into two groups of 200. First group named A individually responded a controlled survey by 6 concepts, 10.08% related their listening to relaxation, 9.22% meditation, 9.04% depth, 9.04% tranquillity, 8.27% peace and 8.1% immersion. Second group named B answered a survey without any restraints, 7.6% wrote tranquillity, 5.9% peace, 4.4% relaxation, 3.4% sea, 3.3% calm and 2.5% harmony.

For exposure the effects of immersive sound perception a significant number of ekphrasis were chosen (10%), the method of selection was made randomly.

Conceptual framework

This section exposes the relationship between the immersive sound perception concepts, ekphrasis, question around the research and the ethical approach in the experiment.

Immersion

Immersion and its auditory perception are located in aesthetic philosophical treatises and psychoacoustic phenomena, as well as in production mechanisms composed of surround sounds and rhetorical mechanisms composed of transitional perceptions.

Some authors propose that immersion can identify stimuli to deepen and describe the sense of commitment of a viewer against a presentation system or technological artifact that produces it (Novy, 2013). From another perspective, immersion is a holistic concept that that refers to its own reproduction from different times such as: visual illusions on the walls of ancient palaces, optical illusions that deceived the viewers through the perspective, shading effects, as well as panoramas, hemispheric projections, virtual reality mechanisms and surround sounds (Grau, 2003).

Along with this, it is possible to define that immersion is made up of different kinds of illusions that have evolved through the time with its technology, independently of the sense perception. This means that perception cannot be conceived without an object that is perceived, and every object is made up of certain qualities that allow us to discern its shape, size, depth, colour, tone, temperature, surface and other sensations that stimulate responses from our senses (Cohen, 1989). Likewise, perceptual activity establishes a series of relationships between elements perceived from different natures composed of magnitudes, forms, transpositions of time in space, anticipations and frames of reference that change with the age of the human being (Fraisse & Piaget, 1973).

The whole process of the immersion is a complex connection of human perceptions. In the psychological perspective the immersion is distributed in two cognitive levels: the perceptive and representative. The first level happens when sensation, attention and perception are empowered through the caption of data, in the second level our imagination, memory and thoughts are connected with the senses (Forgus, 1996).

It can be anticipated that all auditory experience is mediated by imaginary illusions that shape sounds to localize them. Thus, it is possible to research into the perceptual situation of identification and imagination. The philosopher Theodor Adorno wrote: " The music images in the object world only appear scattered, eccentric, sparkling and fleeting" (Beethoven: Philosophy of Music, 2020: 17). Likewise, Toru Takemitsu wrote: “Sound is an image, no matter what the instrument or the composer does” (Confronting Silence: Selected Writings, 1995:43).

Both authors expose a particular form of perception, however, auditory perceptions in their receptive sphere produces different interpretive mechanisms. It has been proven that there is an analytical process for any language (Kellar & Bever, 1980). The authors expose their knowledge in a holistic and transcendental sense, seeking through ekphrasis the essence of listening, there is only a transitional moment of introspection by the act of writing.

In this case, the objective is to delve into auditory perception and the mechanisms for their measurement and interpretation. Therefore, an acousmatic composition with an installation of six speakers created an immersive environment to measure their effects.

Immersive sounds

A sound immersion comes from waves that can be defined by the physical characteristics of an acoustic space with specific attributions. Their bases are given by monaural and binaural signals, afterwards by the number of sources that can amplify its effects and differences.

According to our hearing, an immersive sound can recreate our 360º aural experience and extend the sounds to other perceptual moments from any direction. Likewise, an immersive sound replicates the aural experience and increases the spatial intensity. A unique aspect of the immersion comes from the difference to the traditional listening in a concert hall, where the group of musicians or sound sources are located in the stage, frontally to the listener. In the immersive experience, listeners perceive the spatial movement of sounds (Schumacher, 2021).

Immersive sound can be made up of a minimum arrangement of four independent speakers placed at 90º and located in four corners for a quadraphonic sensation. The perceived depth would result in a bigger sensation. For broad spatial sensations more speakers can help like sextaphonic sound trajectories. The hearing system inside the immersive environment provides us perceptual data and orientation. Therefore, the immersive experience allows us to analyse their interaction between their artifacts and human senses.

Ekphrasis

Ekphrasis is an unconventional form of expression, in other words, it is a rhetorical resource that describes the encounter with the artistic artifact in any form. Its origin comes from the discourse and its tropes, these figures can change the direction of an expression, with another representation.

Another definition comes from rhetorical devices where the speaker evokes images in a mental world (Ryan, 2001). According to Krieger (2000), ekphrasis has its origin in the semiotic desire for the natural sign. The semiotic desire seeks the mediation with the perceived immediacy from an artistic object. As well as a desire that seeks the tangible, or better said, the transformation of what is aesthetically perceived. Theorist and art historian Oliver Grau (2003), defines immersion as an expression of literature, that is, ekphrasis.

Ekphrasis, as literary studies understand it, does not have a specific grammatical form, consequently, it needs to be defined by its content.

Finally, as a rhetorical device is a reflector of perception and a description with discursive references that can be analysed by researchers. Ekphrasis can be distinguished from other polysemic mechanisms that do not have the similar capacities for interpretation and evaluation. As a result, ekphrasis can be a system to capture sensitive data of auditory perception, mediated by sound immersion and its aesthetic content.

Methodology

The analysis of the auditory experiment had a qualitative assessment tool, to produce representative data in a case study. The case study allows us to know a particular situation that we do not know (Stake, 1995). Another perspective proposed it as extensive research with the prevalence of a phenomenon (Silverman, 2013). The case study is a way to organize data without losing the holistic approach. In otherwords, the case study uses different instruments and techniques to capture evidence, their method is validated through triangulation of data.

The triangulation conjugates the phenomenon with other perspectives (Stake, 1995). Their purpose is to validate and contrast the phenomenon with other sources. As an example, there is a definition by the French composer Claude Debussy about his masterful composition *La mer, trois esquisses symphoniques pour orchestre*, or simply *La mer.* He wrote his masterpiece between 1903 and 1905 during his stay in the British Channel in Eastbourne:

> *"I have many memories and they are better than the seascapes themselves whose beauty often deadens thought. My listeners have their own store of memories for me to dredge up" (Cox on Stake, 1995:42).*

With the example, the role of case study is not necessarily to map the world, but to sophisticate its contemplation.

For the purpose of methodology implementation, data were obtained through an auditory introspection in order to understand the effects of sound immersion, in turn, two surveys were implemented. The objectives were to identify patterns of participants consciousness, emotions and perceptions.

The first survey (named A), asked to reflect on listening, choosing six words from a list of 20 concepts related to auditory perception. The concepts were manipulated to express the moment of hearing and write an ekphrasis.

The list of 20 concepts were categorized into perceptual depth, closeness, space, immensity, scale, loudness, immersion, distance, rhythm, noise; emotional: anxiety, harmony, longing, annoyance, incongruity, tension; awareness: relaxation, tranquillity, meditation and peace.

The second survey (named B), asked to reflect and write freely six words to express the moment of hearing and create an ekphrasis.

The same question was put in surveys to implement the experiment: What does the sounds mean for you? It should be noted that 400 people agreed to participate in the study. A group of 200 people wrote the control survey, another group of 200 people wrote freely. The question and the ways of conceptualizing the ekphrasis helped me find out unexpected patterns and compare them to the results.

Furthermore, it was announced that an installation with sextaphonic spatial location within an area of about 310m^2 was available to answer the surveys. In the installation an immersive sound was produced at 51.4dB with an acousmatic composition in continuous repetition (see images 1-5 below).

Image 1. Flyer design for social media queries.

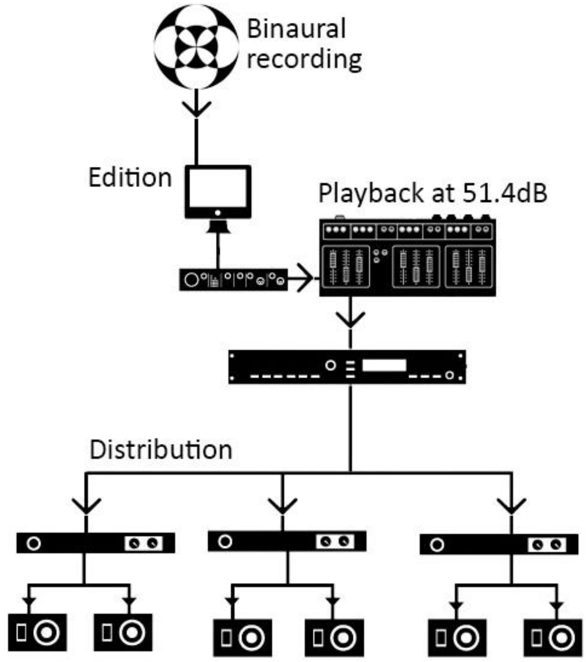


Image 2. Binaural recording algorithm and its layout.

Image 3. Sound installation at Autonomous Metropolitan University in Mexico City.

The presentation of the composition was scheduled from 12:00 to 5:00 pm, for three weeks in May 2022. Listen to an excerpt by clicking here.

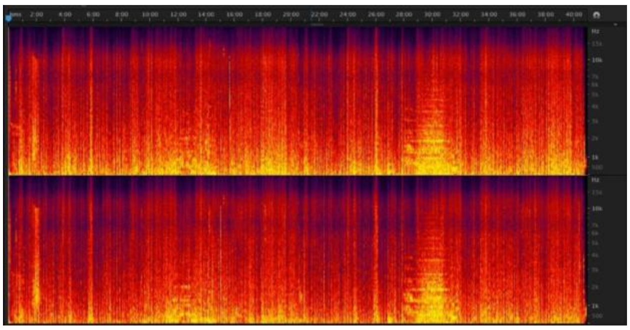


Image 4. Acousmatic composition: Word appropriation hypothesis (Wah). Duration: 40 minutes.

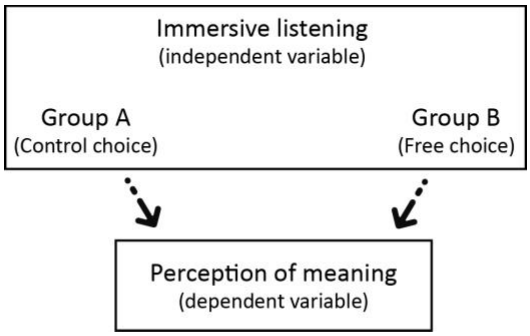
Image 5. Installation and its participants.

Ethical consideration

At the experiment the health of the participants, consent, respect for privacy and confidentiality were taken into account. Therefore, personal information was excluded from the analysis. The qualitative data was used solely for operational purposes in the research.

Results

The resulting data had 400 individual contributions that were triangulated, 200 surveys were manipulated by a limited choice of six concepts in a list of 20 (group A), other 200 were answered by free choice (group B). The purpose was to describe the variations and explain the meanings of immersive perception (see graphic 1 below).



Graphic 1. Variation of auditory perception.

The dependent variable was experientially defined in the question because the prior situational conditions were not available. Even the result in the independent variable data was unexpected, therefore, the interpretive faculties served to evaluate the revelations. Thus, two phases of analysis were implemented with different semantic categories of data collected.

The first phase was the reduction of data through the use of standardised units coding. Having said the above, the units were disaggregated into perceptual, emotional, consciousness, nouns, verbs, properties of nature, terms and their empirical referents.

Consequently, the segments were part of meta-categories and each unit was coded for statistical analysis, their values were defined as percentages to create semantic clouds.

As a result, group A established the following percentages: 10.08% relaxation, 9.22% meditation, 9.04% depth, 9.04% tranquillity, 8.27% peace, 8.1% immersion, 7.92% space, 6.72% immensity, 6.03% harmony, 4.22% distance, 3.96% loudness, 3.79% noise, 3.62% tension, 2.58% closeness, 1.72% rhythm, 1.55% incongruity, 1.38% anxiety, 1.12% longing, 1.12% annoyance and 0.52% scale (see graphic 2 below).

Graphic 2. Semantic contributions of the controlled group A.

Another group wrote 352 concepts with the following percentages: 7.6% tranquillity, 5.9% peace, 4.4% relaxation, 3.4% sea, 3.3% calm, 2.5% harmony, 2% nature, 1.9% waves, 1.8% reflection, 1.5% serenity, 1.5% water and the remaining concepts had lower percentages. The visualization shows the most frequent concepts (see graphic 3 below).

Graphic 3. Semantic contributions without restraints.

The second phase was for data interpretation through the simple random selection of ekphrasis, these were chosen with a fraction of 10% to expose the effects of immersion.

In the selection an inference was made with the concepts: tranquillity, relaxation and peace (see tables 1 & 2 below).

Controlled group (A)
Male 25 years old *"Part of the sounds in space create a moment of relaxation, I feel immersed in a space with a beach and waves crashing, a tranquillity is generated and allows me to meditate. It is a moment of tranquillity that allows me to get away from the daily noise of the city."*
Female 18 years old *"The sounds gave me a feeling like someone very small in this immense world, I felt like everything was very big and at the same time dangerous, but at the same time sound relaxes me. There is a feeling of peace."*
Male 24 years old *"The various sounds give me emotions. First a feeling of being in another space, a large place, this causes an immersion. In addition, it causes me relaxation that leads me to meditate. Also caused me a certain depth of space."*
Male 31 years old *"The spaces of silence and increased loudness allow interaction, people can imagine immersive scenarios, I conceive scenarios close to an ocean and forest. The spaces perceived are real, allowing me to experience their smells."*
Female 21 years old *"The sound of the waves gives me a feeling of relaxation and tranquillity; I was able to meditate and put my negative thoughts and stress aside. It gives me a deep peace of mind to unload everything that makes me feel stressed. I also feel harmony and a sense of well-being, tranquillity and immersion."*
Male 20 years old *"Listening is like being on top of a rock in a storm at night, I felt closeness to the sound and a lot of immersion. I could meditate on the moment."*
Fluid 20 years old *"It seems to me a way of thinking an immersive moment in my mind, my senses were guided, and my emotions calmed down. I felt tranquillity."*
Female 23 years old *"It is an immersive experience that produces a feeling of tranquillity and serenity, at the beginning it started very tenseand decreased in total harmony."*
Male 21 years old *"The immersion surrounds the space and creates a complex moment for meditation. An immense sea invites you to relax where the depth wave catches you. The sonority becomes an ally of the depth, the rhythm and the immense waves take over the sweet yearning for solitude. It is a deep feeling of peace, an aspiration. The hope in our heads and struggles for peace."*
Male 22 years old *"I feel an immersion that moves me into a different place with waves and noise, at the same time everything is distant."*

Table 1. Random selection from group A.

Without restraints group (B)
Female 19 years old *"I feel like I'm in an isolated place, it's quiet and safe, but at the same time it's deep, you don't know where it is and it causes anxiety. At times I felt chaotic but immersive, like a place of peace."*
Male 22 years old *"I feel an infinite peace and at the same time a tranquillity. I feel separated from everything, without any responsibility, I feel peace and calm."*
Female 19 years old *"I feel like I'm in an isolated place, it's quiet and safe, but at the same time it's deep, you don't know where it is and it causes me anxiety. At times I felt chaotic but immersive, like a place of peace."*
Male 22 years old *"I feel an infinite peace and tranquillity. I felt separated from everything, without any responsibility now I feel peace and calm."*
Male 19 years old *"The concepts helped me to feel good about myself, to know that I have goals and I am fulfilling them with every step I take. I believe that more words could express my hearing, but everything may depend on the moment and the situation in which you find yourself. I won't forget this moment."*
Female 20 years old *"The sound gives me peace, it is a place where I can reflect on personal issues, I feel free because and serene. At the same time, I feel active, productive, peaceful and stable."*
Female 21 years old *"The sound relaxes me, I felt surrounded by peace, happiness and nostalgia. The sound invites me to reflect or meditate and brings me a moment of happy memories. It is a beautiful moment for memory."*
Female 22 years old *"To me sound generates tranquillity and peace, the waves sound emits peace, calms my stress, everything becomes bigger when I find myself in this sound garden."*
Female 18 years old *"The sounds that I perceived led me to think about some moments in my life, moments of peace and tranquillity."*
Female 21 years old *"I'm here, in this sound space lying down in the company of the sounds with the sunny and cloudy weather, all makes me feel a calm that relaxes me, I feel good. It is a peace of mind, also the sea is one of my favourite places, its sounds give me a feeling of harmony."*

Table 2. Random selection from group B.

Conclusions

First the sound reality of this experiment was limited by ekphrastic interpretations. This is one of topics of reflection on the consequences of the immersive perspective that tries to understand the cognitive process that supports it. The interpretations are decisive in a problem with deep roots that have been discussed in the philosophy of Kant and Husserl.

According to Kant (1991), introspection allows us to be aware of our own representations. The action of the sound object awakens sensuous perception, which results in a concrete phantasm of the object in the imagination from which the intellectual concept is derived. In other words, it is to possess our own representations.

The psychologist Michael Maher (2018) proposes that introspection informs us about thinking operations, the mind seizes on general features of things, their agreements or differences, the relations of cause and effect, of substance and accident, of unity, plurality, and connexions in space or time. Likewise, designates the modes of perception in the consciousness.

Introspection as a method has advantages that allow an approach to the intimate mental processes, such as perception, emotions, attention, consciousness, feelings, learning and intelligence.

Therefore, auditory introspection can be decisive in understanding self-awareness, even serving as the foundation for acquiring new knowledge, as well designated as a form of thought that is validated in self-awareness.

Coming back to the point, the results made it possible to locate the auditory introspection of an immersive environment at its perceptual and representative level.

The location of each participant in the sound installation did not modify their perception, despite its location in the place for listening (see image 5 below).

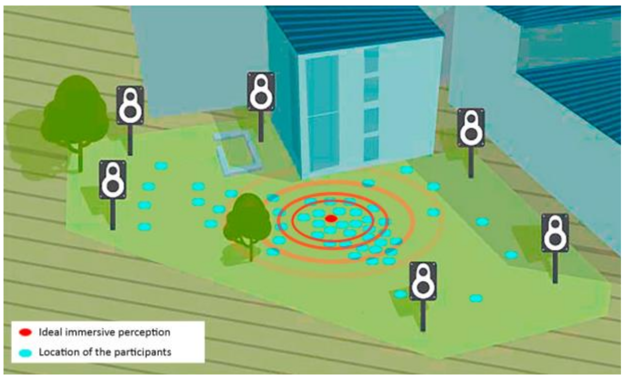


Image 5. Location of the participants

On the one hand, the introspection of the immersive sound produced a moment that was linked to consciousness and emotions. On the other hand, the concurrence of the concepts (tranquillity, relaxation and peace) configured the immersive listening with the independent variable, at the same time they changed the meaning due to its inference with the dependent variable.

An important aspect in hearing was achieved with the creation of the time suspension effect, this resulted in the moment of enjoyment of the listeners and involved the mental construction of a meaningful image with memories and emotions.

Subsequently, the immersion effect emerged, mediated by its cognitive implication.

According to the researchers Ryan, Rigby and Przybylski, the immersive experience is related to levels of autonomy and its variables are related to their own enjoyment (Torres, D., Blanca. E. & Pérez, R., 2021).

Ekphrasis allowed the transmutation of the auditory perception of the sound object to the textual world.

Imagination and perceptions as elements which the inner word is constructed, evoked their domains. In this subjective paradise there were desires, dreams, goals and commitments.

This means that the participants found themselves in the middle part of the immersive phenomenon, place of the cognitive interaction between the sound stimulus and its technological mediation.

The study of thought expressed in the semantic contributions makes this clear, for the disaggregated units into, perceptions, emotions, consciousness, nouns, verbs, properties of nature, terms and their empirical referents symbolize universal notions and abstractions, but abstractions having their foundation in reality.

Finally, ekphrasis as a social practice allowed the introspection to be transformed into textual relationships emanated from binaural sounds and the capacity of listening, empowering the imagination which gives meaning to the human being.

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EZDSP:
From Production to Programming

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EZDSP is an audio plug-in developed for creating custom digital audio effects from directly within a digital audio workstation. Through a combination of dynamically generated code, the SOUL language's JIT compiler, and a custom C++ interface, this software allows users to create and modify digital signal processes on the fly. By removing common barriers to plug-in development, such as the need for an integrated development environment or an extensive background knowledge of C++, EZDSP seeks to make audio programming more accessible to artists and engineers of all backgrounds. This paper will address both the implementation and potential creative uses of this software.

Keywords: Audio Programming, SOUL, Plugin Development, Digital Signal Processing

Audio plug-in development is a multi-disciplinary field that requires a solid understanding of computer programming, digital signal processing, and music. A deep knowledge of C++ is often needed to make optimized plug-ins that can do complex signal processing in real time. Experience in the field of digital signal processing is likely required to design appropriate algorithms. Finally, musical training is often needed to successfully evaluate the sonic output of an audio effect. Therefore, the barriers to entry for aspiring plug-in developers can be quite high.

As such, there is demand for a simplified method of creating digital audio effects, one that reduces many of these challenges. This is the role that EZDSP (Easy Digital Signal Processing) seeks to fill.

EZDSP is a fully customizable audio plug-in that allows users to create their own digital audio effects. EZDSP simplifies the plug-in creation process by breaking it into two parts: The *Component Creator* and the *DSP Editor*. The *Component Creator* handles the graphical user interface (sliders, buttons, etc.), while the *DSP Editor* handles the digital signal processing (DSP).

Creating even the simplest of delay effects as a standard VST plug-in requires hundreds of lines of code, with EZDSP it can be done with four lines and a single component. The following sections of this paper will cover the technological platforms that EZDSP is built upon, how EZDSP works, and several potential creative uses of this technology. The source code, prebuilt binaries, and user documentation can be found at https://geckl.github.io/EZDSP/.

Background

SOUL is the programming language upon which EZDSP's audio processing is built. It is an embedded programming language for writing real-time digital signal processing code that is both fast and memory-safe (Ferrari, 2018). Its efficiency is comparable to C/C++, two languages that are commonly used in audio applications. Yet from a safety and syntax perspective, it has more in common with popular scripting languages such as JavaScript or Python. This combination of speed and safety makes it ideal for DSP, as less focus is needed on code efficiency and memory management.

How SOUL differentiates itself from other languages commonly used in audio programming is that it consists of both a language and a runtime environment. When an application utilizing SOUL is executed, the SOUL code is sent to the SOUL runtime environment, which compiles it and then directs it to the most optimized processor (Storer, 2018). This means that a single piece of DSP code could be processed on a central processing unit (CPU), a digital signal processor (DSP), or a custom hardware device, all based upon what the end user has available at the time.

There are currently two version of the SOUL application programming interface: a high-level abstraction API called *SOUL Patch* and a low-level API (Ferrari, 2021). *SOUL Patch* is a JIT-compiled plug-in format that functions similarly to a standard VST/AU plug-in, consisting of audio input/output, MIDI input/output, and parameters. The low-level API allows for more custom interactions with the SOUL language. It consists of both a *performer* that JIT-compiles SOUL code, and a *venue* that asynchronously runs SOUL code. Neither of these APIs provide any graphics, instead leaving GUI rendering to the application hosting the SOUL code.

In addition to the core language, SOUL comes with a series of tools and helper classes which allow developers to easily integrate the language into their application. This includes header-only classes for host applications interfacing with the *SOUL Patch* format, command line scripts for conducting unit tests, and a Visual Studio Code extension. Finally, it includes code for a JUCE plug-in that can dynamically load and run different SOUL Patches. This SOUL Patch Loader Plug-in is the basis upon which EZDSP is built.

EZDSP Technical Overview

At its most basic level, EZDSP functions as an abstraction layer, facilitating communication between a SOUL patch and a digital audio workstation (DAW). EZDSP is a standard C++ audio plugin created with the JUCE framework, consisting of a graphical user interface and an audio processor. This audio processor inherits a SOUL Patch Audio Processor (provided as part of the SOUL Patch API) that wraps a SOUL Patch within a standard JUCE audio plug-in instance (Figure 1). This abstraction layer allows the EZDSP Source Code to communicate with the SOUL Patch regardless of the input/output layout of the track it is placed upon.

SOUL Patch

A SOUL patch consists of a .soul file, which contains the SOUL plug-in's source code, and a .soulpatch file that contains the patch metadata. EZDSP autogenerates both of these files at runtime, and updates the .soul file automatically whenever the user makes changes within the EZDSP plugin.

A .soul file contains at least one SOUL Processor that processes audio on a per-sample basis. During playback, EZDSP relays audio to and from the SOUL Processor, along with other relevant values provided by the DAW such as project information variables (time signature, tempo, etc.) and automation data. EZDSP constantly updates these values based on the current playhead information.

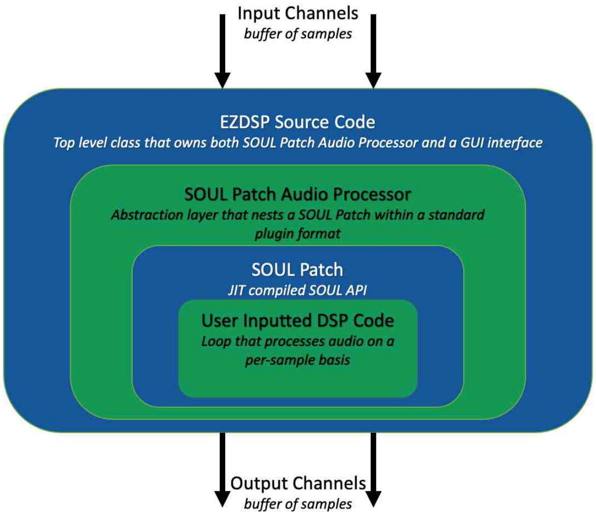

Figure 1. EZDSP Code Flowchart.

The .soul file that EZDSP generates contains a single SOUL Processor called Main. At the top of the processor is the declaration section, where all global variables are declared, including both built-in project information variables and user-defined component variables.

Below this is the implementation section, where audio samples are processed inside a *run()* function that is called upon playback (Ferrari, 2021). This function contains an infinite loop, which is executed on a per-sample basis. Within this loop is the DSP code section, where user-written DSP code is executed.

Making Audio Effects With EZDSP

EZDSP is comprised of two main features: the *Component Creator* and the *DSP Editor*. The *Component Creator* provides a graphical interface for generating common objects such as sliders, audio buffers, and buttons. The *DSP Editor* is where users write code to process incoming audio samples. Components created via the *Component Creator* can be accessed in the *DSP Editor* through a variable that shares the component's name.

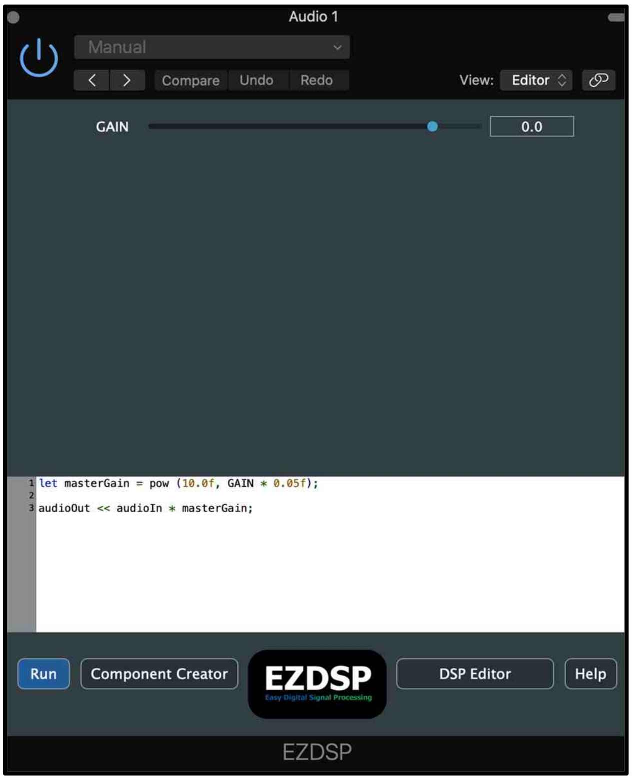

Figure 2. EZDSP Main Window. The DSP Editor is embedded on the main screen as shown, while the Component Creator opens in a separate pop-up window.

The Component Creator Window

The *Component Creator* window allows users to create sliders, buttons, audio buffers, and numbers. These are global components, and as such their value is only reset upon recompilation of the EZDSP plugin. These variables are created visually through forms, and the accompanying source code is dynamically generated at compilation based on the inputted parameters. Component names may only contain alphanumeric characters and underscores.

Component	Name	Type	Min	Max	Init	Step	Size
Slider	Feedback	Float	0	100	0	1	
Buffer	DelayBuffer [DelayBufferIndex]						44100
Button	FeedbackOn						
Number	LowPassFreq	Int			500		

Table 1. Component Table.

Components are presented in a table within the *Component Creator* window (Table 1). This window allows the user to keep track of what components have been created, as well as delete any that are not needed. The four component types function as such:

SLIDER: A visual component that creates an input stream of floating-point numbers, which is constantly updated to reflect the current position of the slider. This component takes five parameters from the user:

- Min: the lower limit of the slider's range
- Max: the upper limit of the slider's range
- Init: the initial value of the slider
- Step: the increment between slider values
- Name: the slider's variable name

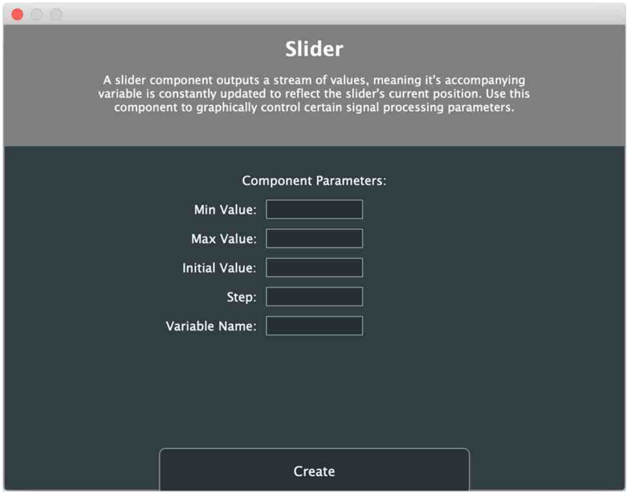

Figure 3. Slider Creator Window.

BUTTON: A visual component that creates a simple binary switch (0=Off, 1=On). This component takes only a single parameter from the user:

- Name: the button's variable name

BUFFER: A component that stores an array of either integer or floating-point numbers, which are all initialized to zero values. Additionally, a buffer component comes with a memory safe indexer that wraps all values outside the buffer's size. So, for example, a buffer created with the name *DelayBuffer* would be initialized as an array, along with an accompanying wrapped integer variable of the name *DelayBufferIndex*. This component takes three parameters from the user:

- Type: the type of values stored in the buffer (int or float)
- Size: the number of values stored in the buffer
- Name: the buffer's variable name

NUMBER: A component that stores a single integer or floating-point number. This component takes three parameters from the user:

- Type: the type of value stored in the number (int or float)
- Init: the initial value of the number
- Name: the number's variable name

The DSP Editor

The *DSP Editor* allows users to write custom digital signal processing code using the SOUL language. It features custom syntax highlighting, which color codes SOUL types, operators, keywords and comments, as well as user-defined components.

Code written in the *DSP Editor* exists within a loop that processes one audio sample at a time. The reserved variables *audioIn* and *audioOut* store the plug-in's input and output streams respectively. The << operator is used to write a value to an output stream:

```
audioOut << audioIn * masterGain;
```

Users have full access to both SOUL's intrinsic functions (operators, indexers, etc.) and its various namespace libraries (::filters, ::mixing, etc.). Additionally, EZDSP provides a variety of additional built-in variables to utilize, such as SAMPLESPERBEAT and CURRENTSAMPLE:

```
let masterGain = soul::dBtoGain(GAIN);
let quarterCount = CURRENTSAMPLE/SAMPLESPERBEAT;
audioOut << audioIn *(masterGain+(quarterCount%4));
```

It's important to note that because this code exists within a loop, any variables that are declared in the code editor will be reset for each sample by default. This is extremely inefficient for certain variables that don't need to be updated every iteration. To create variables that update periodically, use an inner loop to process chunks of audio, calling *advance()* to move forward each sample and *continue* to jump back to the top of the loop:

```
Let distortionFactor = w * (1 – pow(2.781, v) % sampSize;

loop(1000)
{
   audioOut << audioIn * distortionFactor;
   advance();
}
continue;
```

Saving and Loading Presets

Users can save their custom plug-ins as presets in the same way that any other plug-in would allow users to save their settings. However, while standard plug-in presets contain a simple set of parameter states, EZDSP presets represent a completely unique audio effect. So, while users can save and load EZDSP effects, they will always be loaded with the same initial values as defined in the *Component Creator*.

Automation

Due to the way in which DAWs handle automation, it is not possible to add or remove automatable parameters after a plugin is placed on a track. For this reason, EZDSP creates five generic automation parameters upon initialization, and then attempts to customize them to fit the currently loaded audio effect. As such, EZDSP only supports automation for up to five sliders. Additionally, the ability to rename automation parameters is DAW dependent, so while some DAWs will display a parameter label that matches the slider's name, others will display a generic label.

Potential Uses

DSP Prototyping

EZDSP seeks to improve the process of rapid DSP prototyping by providing an environment that is both compatible with popular music software, and designed specifically for audio. SOUL's JIT compiler and EZDSP's built-in text editor allow engineers to tweak DSP algorithms and immediately hear the result of the change, without even having to pause playback. This enables rapid design, review, and refinement, by removing the need for constant recompilation of the entire codebase. Additionally, by programming within a DAW, engineers will have access to a wide range of metering and analysis plug-ins that can assist in the design process.

Learning Tool

There is a demand for educational tools that bridge the gap between the more creative side of music technology curriculum (music producing/mixing) and the more technical side (digital signal processing/audio programming). EZDSP seeks to bridge this gap, providing students with an avenue for learning highly technical concepts within a creatively stimulating environment. By stripping audio processing down to its most basic components and minimizing the amount of necessary code, students can focus solely on signal processing algorithms. This simplification makes it easier for users to comprehend the underlying DSP technique. As such, EZDSP can function as an effective learning tool for beginner audio programmers, especially those without previous programming experience.

Future Work

There are several updates to be added in the near future that will expand and improve EZDSP. First, an updated *DSP Editor* will be introduced. This text editor will include a code completion feature for providing users with function headers. This update will also include improved error reporting, giving users the exact location at which their error occurred.

Second, a future update will include an export feature that will allow users to export their effects as standard C++ plug-ins with the click of a button. It is already possible to translate SOUL code into C++ code using the SOUL command-line tool. EZDSP will further simplify this process by automating the build of this plug-in into standard formats such as VST3 and AU. The SOUL command-line tool provides other useful features, such as the ability to generate WebAssembly implementations of patches. This can be used in the future to develop a version of EZDSP for online DAWs.

Lastly, there are plans to integrate an ezdsp:: namespace into the codebase for users to access. This namespace will include a variety of mathematical functions that will bring EZDSP closer in functionality to popular digital signal processing tools such as MATLAB. Many of these techniques are built into the fabric of the SOUL graph structure, and as such can be optimized by the SOUL runtime environment (Ferrari, 2018). These functions will expand the research capabilities of EZDSP, allowing users to utilize a variety of transforms, interpolation techniques, and matrix manipulations that are not included with the standard SOUL language.

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Computer Aided Composition
Broken Cane

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This paper presents a scheme for the composition of the piece for percussion "Broken Cane". The process of the composition is derived basically from diatonic theory and mathematical operations exposed by John Clough. In addition, the work uses stochastic process and self-similarity ideas derived from new mathematical concepts. "Broken Cane" was composed with the idea of a live performance and a live signal processing of the basic material. This composition *uses digital signal processing and effects with an overall plan to distribute the sound over a set of 8 or 4 loud speakers in the performance concert hall.*

Keywords: Computer Aided Composition, Diatonic Theory, Contour, Set Group Pitch. Live DSP. Space

1. INTRODUCTION.

Several composers used some numerical relations to write music pieces, but methodology and algorithms have been formalized in the 20th century to help CAO/CAC composition, as in the examples of Hiller, Xenakis, Barbaud and others.
With the coming of the computers appeared mathematical theories derived from statistics, new mathematics and fractal linguistics, group theory, generative graphs, neural nets, Markov chains, genetic algorithms, machine learning.
Mathematics has made possible the generation of formal structures and the generation of constituent elements of macro and microstructure.
"Broken Cane" is composed with the help of theories derived from numeric relationships. These relations generate the generation of notes, rhythms, and elements of structure and formal development.
There are deterministic elements and random elements. Elements that came from statistical procedures, the introduction of 'top-down' recursive grammars, and the adaptation of problem-solving techniques from Artificial Intelligence

2. SET THEORY. CONTOUR. GESTALT.

New concepts from AI include concepts derived from Set Theory and Contour Theory. Allen Forte write the "The Structure of Atonal Music" with notes derived from Milton Babbit twelve tone theories.

The concept came from mathematical set theories with a numbers of operations.
Broken Cane is composed with techniques that came from set theory, contour theory and principles derived from Gestalt Psychology of Perception

2.1 Set Theory.

Theory is the analytical technique we will use to analyze music from the XXth century and with special inters in atonal music.
A Set Theory study sets as a collection of objects. It was introduced by George Cantor in 1870.
Its basic fundament is binary relations but include operations as

-Union
-Intersection
-Set difference
-Symmetric difference
-Multiplication
-Power set

This theory was generalized and it was used in studies of Semantics, AI and Music Analysis.
In music was introduced by Howard Hanson and later Allen Forte introduced set combinatory operations as Permutations, Transposition, inversion and complement.
Musical set theory is more closely related to group theory and combinatorics than to mathematical set theory.
Operations on ordered sequences of pitch classes also include transposition and inversion, as well as retrograde and rotation.
Rotation of an ordered sequence is equivalent to cyclic permutation.
Operations also include symmetry operations.

2.2 Contour.

A musical pitch contour describes a series of relative pitch transitions, an abstraction of a sequence of notes.
The pitch contour of a sound is a function or curve that tracks the perceived pitch of the sound over time
In music, the pitch contour focuses on the relative change in pitch over time of a primary sequence of played notes. The same contour can be transposed.

2.2 Gestalt theory.

Gestalt theories give us a methodology for identifying, classifying, and interpreting "musical gestures.
The classification of musical gestures is based on theories of form perception taken from Gestalt psychology.
A gesture may be developed and transformed, and the profusion of related gestures imparts spatial coherence to a work of music as a unitary gesture.
Basic concept of gestalt derived from contour theories give us elements for analysis and composition:

SG spatial gesture
CSEG contour segment
PS point shift

A spatial gesture emerges from the consecutive activity of multiple performers within an ensemble. Various gestures are differentiated by the specific orderings, in time, of sonic events occurring at separate points in ensemble space.
The idea gives us proximity and similarity based on Tenney and Polansky.

3. BROKEN CANE.

Broken Cane is a piece for marimba and vibraphone.
The basic methodology for the composition of the piece came from diatonic theory, group set and self-similarity procedures. The main idea came from numerical relations that establish a contour that is the basic for the entire composition.
The composition has tree movements where the third is a reconstruction of the early movements.
The numerical relation in the work has different set pitches groups.
The paper is centered in the structure that controls the pitch contour, the rhythmic development and the formal structure.

3.1 Structure.

The development of music is always associated with the development of time. Different styles provoke different forms to understand the flow of music.
The idea of structure in recent music history, came from Henrich Schenker´ s concepts as introduced by Alen Forte´s The theory of Atonal Music.
Western music and non-western music styles have devised different forms of structure over time
The general structure in Broken Cane derives from the same concept and set group that introduced in the melodic line and in the rhythmic development.
The Concept of the piece Broken Cane came from the idea of mosaic development derived from authors as Debussy, Reynolds and others. In order to adjust the different units of numbers and the entire piece is necessary to use the classical concept of minimum common multiple and greatest common divisor.
The entire score is divided into section following the contour of the basic set group.
The general structure in Broken Cane derives from the same concept and set group that introduced in the melodic line and in the rhythmic development.
The entire score is divided into section following the contour of the basic set group.
Each movement is divided into sections and it follows top down grammars theories

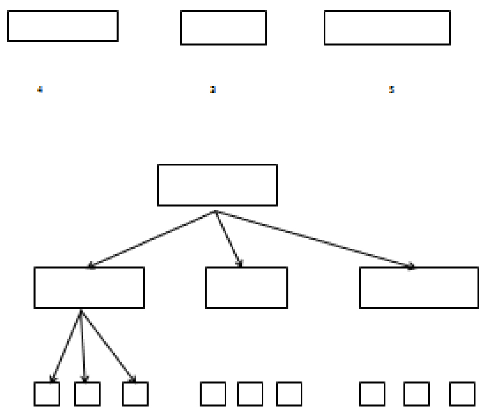

Figure 1. Top Down structure.

3.2 Digital Signal Processing

The composition will have and electronic sonority realized with synthesis techniques and a DSP live process from software adequate as PD and / or MAX.

3.3 Space

The sound file can be processed with cutting and distribution of fragment over a set of speakers.
The ideal will be 4 speaker/8 speakers around audience.
The distribution can be realized with stochastic process and /or triggered from pedals for the performer.
The electronic implementation is designed in Pure Data and can be controlled for the performer or a sound technician in the audio mixer with a single click in every section

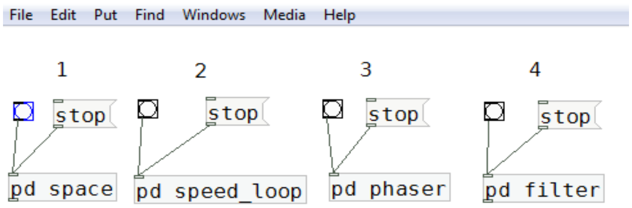

Figure 2 General Patch

The piece will have 3 movements with a mosaic structure using loops and repetitions..
Simultaneous loop can produce a delay and phasing of motives in different speed and tempos.
This can give the possibility to change tempos and speed.
There is an influence of Ligeti´s micropolyphony and Nancarrow´s irregular meter.

There are some characteristics of this composition:

-Live percussion against pre-recorded sound and /or live recording sound
-Continuum and background over the performance space
-Continuum background notes and chords
-Modulation and timbre variations
Electronic and DSP processing

4. CONCLUSION

Broken Cane is a piece written with methodology derived from concepts of new mathematics but with musical principles in the process of the composition the mathematics, AI and software and algorithm must be always used with the idea of music and artistic identity.
Concepts derived from Diatonic Set Theory and Computer Assisted Composition are also used to compose the piece Broken Cane.
AI is a discipline that can use several process derived from several mathematical concepts.
AI, software programs and algorithm must be considered always as an aid for composition, (computer aided composition) .
It should be noted that without prejudice to software or theories, the final work must have a relevant artistic entity.

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Some considerations around time in electro-acoustic music

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In this article we've analysed some time concepts, applying them to a selection of electroacoustic pieces of different aesthetics.
Some differences are pointed out: between hors-temps and en-temps with specific application to the repertoire; the relationship between χρόνος (Chrónos) and καιρός (Kairós) and their influence on the compositional experience and on the approaches used to analyse electroacoustic pieces. The fact that acousmatic music is characterized by a sufficient degree of abstraction with reference to the more traditional musical parameters, does not lead us to the conclusion that the management of time cannot be also considered at an analytical level.
We've cited Obst's Crystal World cycle as an emblematic case. In this cycle, time and its management are important on a multidimensional scale: this leads us to make further considerations on analytical techniques, its limits and its possible developments.
Other references concern the musical repertoire by J. Adams; J. Alvarez; F. Bayle; F. Donatoni; J. Harrison; R. Minsburg; F. Otondo; M. Rodrigue.

Keywords: Rhythm; Time; Acousmatic; Composition; J. Adams; J. Alvarez; F. Bayle; F. Donatoni; J. Harrison; R. Minsburg; F. Otondo; M. Rodrigue; M. Obst

1. «Hors-Temps» and «En-temps»: the management of time

From the point of view of a composer, the time of a composition is never just the timing of a compositional work, but also the time that logically precedes its achievement.
With the term «Hors-temps», we define the time that precedes and regulates the development of a musical piece, influenced by the composer's vision.
Opposed to this we have the work «En-temps», that is its sound incarnation, or rather its translation into performance, or fixing on tape. While talking about «hors-temps», E. Napoletano distinguishes: the «hyletic universe», which is the «material universe» and the «universe of forms», which are:

> The rules of composition, construction, musical architectures at all levels starting from micro to macrostructures (…). These systems can be considered as formal islands. The entities that deal with this universe are emancipated from their historical conditions of birth and time - since time itself can be treated in its temporal immobility (Napoletano, 2018: 294-297).

Eg.1 With Quartetto III (Avantaggiato, 2014: 2-11), the Veronese composer Franco Donatoni wrote a piece that was largely influenced by Serialism.
The composer started from the definition of a «frequency scale» - «scala delle frequenze» in Italian – subdividing the octave in constant intervals of 14 frequencies. The initial «material universe», described by Donatoni as a qualified and well-characterized sound material, offers many other transformation possibilities, allowing the composer the «leavening» of the materic substrate.

Eg. 2 In the Anthology Night Studies by F. Otondo the «hyletic universe», is represented by a wide palette of percussive sounds of the Javanese gamelan orchestra.
The composer here built some nocturnal soundscapes characterized by many darker, atmospheric ambient moments and the presence of a powerful rhythmic percussive elements.

Eg. 3 In Crystal World, German composer M. Obst investigates into the complexity and dynamism of the sound spectra of the Asian instruments and the human voice. These sounds encourage the artist to open and relax them, to create a formal development in 4 panels.
Obst describes a journey that goes from sound to noise: he plans not only the set of frequencies he is going to use, but also the differences amongst them. With the fourth ratio ($40\sqrt{2}$), Obst obtains sequences of sounds close to noise (Fig.1).

5√ 2	10√ 2	20 √2	40√ 2
100 (hz) 114 132 152 174 …….	100 (hz) 107 114 122 132 …….	100 (hz) 103,5 107 110,7 114 …….	100 (hz) 101,7 103,5 105,3 107 …….
Divide the octave in 5 intervals.	*Intervals are slightly Larger than a second*	*Intervals are almost a quarter of a tone*	*It leads to sounds close to noise*

Figure 1: Frequencies Ratios and Intervals - Harmonic system in Cristal World.

Instrument	Attack	Release	Colour
Rotating Sound Plate (Java)	Smooth	Very Long Stable overtones	Very warm
Keysu (Japan)	Medium	Medium: the spectra soften during release	Warm
Rîn (Japan)	Medium	Long release. Stable overtones	Bright, rather cold
Glissando Gong China	Medium	Short release	Cold, Aggressive
Mokusho (Japan)	Hard	Very short release	Extremely aggressive

Figure 2: «Material universe» in Crystal World.

Subsections	Instrument	Gesture/ texture	Reverb
0'00''-0'31''	Rin, Keysu, Gong	Gesture+ Texture	Room I (Brighter)
0'32'-0'48''	Mokusho	Gesture+ Texture	Room II (Intermediae Brilliance)
0'49''-1'32''	Rîn, Keysu, Gong	Gesture+ Texture	Room I
1'33''-2'17''	Rîn, Gong elect. trasf.	Texture	Room III (less bright)
2'18''-2'34''	Soundplate (2'18'' - 2'33''); Glissando Gong (2'31-2'34'')	Texture + Gesture (ending crescendo)	Room I

Figure 3: Crystal World I - Structure of the introduction: Instruments; gesture/texture; reverb.

2. «Chrónos» and «Kairós»

The time of a work enjoyed by the audience is based on a dichotomy: absolute vs perceived time or, alternatively, chronological vs cariological time.
In various ways these distinctions have been endorsed by composers and professionals of electronic music because the correlation between the perspectives of absolute time and psychological time, even if not always recognized, are crucial to their craft. Schaeffer talks about duration as a psychological and perceptual experience of time; similarly, Olivier Messiaen distinguishes between chronometric or "measured time" and duration or "perceived time". Cairological time, instead, tells us about time as an opportune moment, an instant of occasions, the mature time to perform an action or to make something happen, the inspirational moment in which you can dare and grab the divinity Kairós by the tuft, which is in front of his forehead. Thaut refers to «Kairós», as:

> a temporal dimension of meaning, which informs about the correct understanding and interpretation of events,perceptions, actions and cognitions (Thaut, 2007: p.20).

Attempts to systematize the various time scales that refers to chronological time were presented by various authors (Roads, 2015; Pasoulas, 2020; Andean, 2015). Unlike Curtis Roads, A. Pasoulas (Pasoulas, 2020: p.223) distinguishes between absolute time and psychologycal time to start a discourse around perception.
Instead of talking about a number of time-scales, he talks about a psychological time continuum: at the exact center of the continuum there is balance, where actual and measured duration is supposed to be equal to psychological – perceived - duration. Pasoulas distinguishes some factors that influence time perception which can be related to music or that originate outside music, such as the surrounding environment at the time of listening and the psychological state of the audience listener.
These factors were considered in Par. 4/6 to make some consideration around time modulation and rhetoric in electroacoustic music.
Through a coordination of different approaches Andean (ANDEAN, 2015) instead, coordinates theorists' and researchers' positions in a wide range of fields - from acousmatic to broader areas of musicology and further cognitive research - limiting the number of thresholds proposed by Roads from nine to four (infinitesimal/subsample; sound object/mesostructure; macro; supra/infinite).

3.Time modulation through techniques

Regardless of the number of time thresholds identified or identifiable, what is important for a composer is the possibility to modulate the perception of audience, the sense of time that passes and the overall qualitative listener's experience through some strategies that work at different levels: Micro-structural; Meso-structural; Macro-structural and so on:

- **Change of state:** leaving the initial state and subsequent return to an initial state can be an indicator of time passing.

  Eg.1 - In Klang by composer J. Harrison (2000), the listener can trace the development of the material from casserole sounds in the introduction (0'00''-3'04''), through more complex and higly transformed events in the four sections, back to the opening sound-world in the Coda (7'42''->end).

  Eg.2 - Klang is similar to Crystal World for its programmatic and essayistic approach; however, Klang and Crystal World are also similar for the common strategy to introduce the original materic substrate at the beginning of the work. In Crystal World I, Obst introduces the Asian instruments which are, later in the passage, the object of electroacoustic transformations (Fig. 2-3).

  Eg.3 - In Cristaux Liquide, Mario Rodrigue describes a sonic continuum inspired by two different physical states of water — the solid one, with its fixed, crystalline movements (5'58''-6'15'') and the liquid state (2'39''-3'26''; 5'35''-5'40''; 8'19''-8'53''), with its rich undulations, created in a counter-pointistic way, and the evocation of the avalanches of color characteristics of crystals (2'25''-2'55''; 3'45'-4'13'').
- **Alienation of chronological music structures**: in acousmatic music the trend to alienate chronological time structures is quite common when the objective of the composer is to recall traditional popular music and try to reinterpret it: by doing so, the composer tries to avoid straight pulsation.
  In Mambo à la Braque (1991), J. Alvarez creates an electroacoustic collage of musical segments drawn from Cuban mambo Caballo Negro by D. Perez Prado. Original phrases are re-allocated to create new epileptic musical sequences: the original rhythmic structure of the mambo is variously deviated and the dynamic contrast is increased.
- **De-phasing of rhythmical structures:** the process of dephasing is generally exploited in a more organic way inside minimalism boundaries. Very common in Steve Reich's production, it is also used by J. Adams in Hoodoo Zephyr and by M. McNabb in some episodes of Invisible Cities. Outside the boundaries of minimalism, this technique is used, for instance, in the Entrée of the Messe de Terre:

  > We hear a very elaborate musical composition, which is gradually polarized on two static elements: a monotonous psalmody of the act of confession and a rhythmic cell which is like the lung of this sequence. This is the sound obtained by the friction of the metal grid of a microphone on the rotating plates of a tape recorder. This squeaky sound, with its characteristic pedal, enters a close relationship with the pendulum movement of the windscreen wiper: the distinct rhythmicity of these two mechanical and repetitive phenomena can meet, out of phase. (Chion, 2016: 50).

This example shows that some specific compositional strategies can help to modulate the perception of time, and this is specific but not exclusive of a certain genre.

- **Perceived Timbre, Pitch, Duration, Amplitude, Space work as articulators of rhythms** [Christensen, 1996: 100] **and perceived time**. **Perceived timbre, for example, can help in horizontal organization,** influencing the perception of time passing (Hirst, 2003, p. 2): changes in timbre can affect the integration of a horizontal sequence: repeated and/or rapid changes in timbre can fragment a sequence; less rapid shifts in timbre can be used to delineate larger horizontal units or phrases.
- **Variations in Intensity:** if we concentrate on the perception side, Christensen gives some important advices with regards to working on – what he calls - the micro-temporal dimensions - Space, Intensity, and Timber - and macro-temporal dimensions - Movement, Intensity, Pulse. In particular:

  > Variations in intensity can be used to provoke arousal of the listener's attention; the timbre allows to identify a sound; by altering some of its characteristics, and with some technical retractions, it allows to hide the original sound, making it more difficult to recognize (Christensen, 1996: 12-16). In general, movement allows to increase the awareness of time passing and therefore to make it emerge; the pulsation allows to increase the awareness of regularity (Christensen, 1996: 49-50).

- **Motivic Contrast:** in *Fábrica* (1997), M. Obst uses the motivic contrast as a tool to build the piece together with the following: increase of density or frequency of sound elements over time; general change in sound, through sound selection and extraction; its arrangement in clusters or to create polyrhythms (Obst, 1997: 155-159).
- **Duration and Sustained Sound:** in cases where long sustained sounds are involved and there is little or no indication of long-term evolution, the listener becomes less aware of time passing. However, if there are no cues or clues in the sound itself to make us aware of its approximate physical duration, the sound in question appears seemingly endless, or even static (Pasoulas, 2020: 222).
- **Use of Dynamic Contrast amongst panels:** as a tool to determine a formal development of a piece.

  Eg.: Studien II by K.H. Stockhausen; Fábrica by Obst; Mambo à la Braque by J. Alvarez.
- **Change of density or of frequency of sound elements over time**; **increasing of the complexity of the structures:** a) Working on the relationships among order and disorder, an aspect which is very similar to traditional harmony; b) Working on horizontal relationships amongst objects: layering, like traditional counterpoint (Emmerson; Landy, 2012: 4).

- **The use of different psychoacoustic effects (Reverb; Delay; Filters…)**: reverbs allow the composer to simulate different ambiences/scenes that give an idea of contrasting temporal and spacing coordination.
These techniques were used in pieces from the past, such as in Ligeti's *Glissandi*, to present times.
- **The generation of time:** In *Tilt* by composer Mario Rodrigue, a Francis Dhomont pupil:

> The possibilities of envelope control and the creation of liquid or cloud-like musical morphologies suggest a view of rhythm as a continuously flowing, undulating, and malleable temporal substrate upon which events can be scattered, sprinkled, sprayed, or stirred at will.
> In this composition it is not a matter or filling or dividing time, but rather or generating it (Roads, 2015: 59-60).

Other important strategies can influence the qualitative perception responses of a listener:

- **Emergence of a symbolic and rhetoric substrate,** not limiting this to the categories clearly labelled as rhetoric by some analytical theories: Roy's Relation and Rupture Categories (Roy, 2003); Temporal Semiotic Units and Spatio-Temporal Semiotic Units (M.I.M.,1996).
- **Activating synesthetic relationships**, acting on some characteristics of the sound, such as rugosity (eg.: our work Atlas of Uncertainty, 1'31''-1'47''; 1'53''-2'02'').
- **Working on predictability of events:** in the work «Sweet Anticipation: Music and the Psychology of waitation» the author highlights the predictability of events in time (Huron, 2006, p. 35). He provides the foundation of our perception of rhythm and meter and suggests several sources for this predictability: periodic metric structure; rhythmic motifs; the regularity of musical phrases or the regularity of non-periodic sequences. He demonstrates – through experimental methods – that events occurring at predictable points in time are more quickly and easily processed by listeners.
- **Creating a sense of time abolition:** in «Techniques d'écriture sur support», in the paragraph «Transformations» the author describes how composers can create a sense of time abolition: suspended time («le temps sustendu») or the frozen time (« temps gelè ») can obtained by creating a hypnotic phenomenon as in Asian Music (Vande Gorne, 2018).
The idea of suspended time seems to recall what Christenesen expresses talking about the «time of being»:

> The «time of being» is the time experienced in nature when we are not expecting something to happen, and we are not impatient for a change to occur (Christensen, 1996: 49-50).

- **Another way to create a sense of time abolition consists of playing on contrasts**, alternating sequences where time is compressed, accelerated, rich in events and sequences where there is a sound - a very small loop – that creates the cinematic effect of «shutdown on image».

Other strategies can help composers to manage the intermediate structure of a piece:

- **Sculpting sonic material into gestures or phrases**, which are the middle layers of musical structures:

> We remember discrete entities more easily than continuous or unclearly demarcated ones, at least for the memory of structures.
> This does not mean that continuous variation is not important in the appreciation of musical form.
> It is certainly vital for expressive variation of musical gesture (Bregman; McAdams; 1979: 24).

- **Sectioning of a lengthy piece:** composers have found a solution to presenting excessive macro durations to audiences by dividing their lengthy pieces. This is the case of Messe de Terre by M. Chion (duration 152:30) divided into 16 conceptual blocks.
- **The use of pause/silence as a formal signal**: in Fábrica and Quartetto III a pause divides the work into two equal halves. This is a clear formal message, that allows to give breath to composition.
In Quartetto III, after the central pause, the original series is exposed. In this way, original material does not appear at the beginning of the piece like in Klang by J. Harrison and Crystal World by Obst; but it starts exactly in the middle of the piece.

4.Acousmatic music and its multidimentional rethoric

The question of the presence of a precise musical rhetoric within the acousmatic genre *stricto sensu*, is a bit set aside or even avoided, even for the complexity that a discussion on this topic would entail.
Even if many good reasons exist to discuss sound and music from the angle of a rhetoric and composition, we don't do this very often.
That is probably because analysing acousmatic music from a rhetorical perspective means embracing many uncertainties:

> It means diving into the weird ways that music is and it is not like language, with its syntactic articulation, the ways it does and does not guide our emotions, and the subsequent conclusion that much of musical meaning is wrapped up in the associations we bring to it as listeners (Stedman, 2012: 46).

Therefore, the existence of a rhetoric cannot be denied, being highlighted by various theorists.
It operates at different levels and it has the power to lead the audience's listening; it allows to give a directionality to

music, from sound objects to space organization (Fig.4):

Temporal Associations	Authors
Temporal associations of sounds, carried through their semantic meanings	Functional Grid (ROY, 2004: 358-365); T.S.U. (MIM, 1996: 1-96)
Temporal associations of sounds, carried through their spectro-morphological characteristics	(Smalley's Spectro-Morphology - SMALLEY, 1986: 61–93)
Temporal and metaphoric relationship between audio and other media (such as Video; Poetry/Text), or more synthetically; multimedia or intermedial relationships.	(REES, 2018); (COOK, 1998); (CHION, 2013); (CARTERETTE/KENDALL, 1990: 129-164); (LAKOFF/JOHNSON, 1980: 26)
Temporal associations of sounds during space segmentation and during spatialization processes; treatment of space and spatial movements	Spatio-Temporal Semiotic Units (MIM, 1996: 1-96) Spatiomorphology (EMMERSON/LANDY,2012,4); Figure d'éspace (VANDE GORNE, 2002: 9-11).
Relationship between reality and imagination	LAKOFF/JOHNSON, 1980: 26
Emotional responses of the listener to music stimuli	Network of relations in the interpretation of acousmatic music (HIRST, 2003: 4); Social, Emotional and Meaning-related aspects (EMMERSION/LANDY,2012:5)

Fig. 4: Rhetoric in acousmatic music.

With regards to listener's emotional responses we should observe that:
a) music rhetoric embraces the confluence of emotion and meaning;
b) beyond being kairotic and culturally rooted and situated, musical meaning is "associative", latched necessarily onto the imagination and interpretation of listeners;
c) the comprehension and enjoyment of a given audience has often much to do with audience members' familiarity with the genre;
d) every change in a sound will change the meaning and the perception of a sound; of a phrase or of a sequence, etc;
e) to a large extent, the meaning of a work cannot be controlled, regardless of the intention of composer.
With regards to temporal association the M.I.M. researchers, led by François Delalande, have suggested introducing meaning in the description of sound objects. They defined some Temporal Semiotic Units, that allow us to indicate phenomena of repetition; stagnation, chaotic effects (Invariant T.S.U.s) or otherwise variant T.S.U.s with uniform development, with thwarted development or disrupted balance etc..
The balancing between Variant and Invariant T.S.U.s is a good index of how the composer can work on the continuity or on the variation of music. The term rhetoric is explicitly used by S. Roy (Roy, 2003: 358), in his Functional Grid (Fig. 4), a model in which the author talks about two archetypes of rhetoric:

- **Rèthorique relationelle**: Appel->Réponse; Annonce ->Rappel->Thème et variation; Anticipation /Affirmation; Reiteration/Imitation etc;
- **Rèthorique de rupture**: Dèviation; Parènthese; Indice: Articulation; Rètention; Rupture; Spatialization etc

Eg,1 - In Minsburg A tu memoria, the first section of the piece from 0'00'' to 2'22'' is built around a system of rethoric replies: Appel->Réponse, the first of whom is situated at (0'01''->0'07'').
The answers in the continuation are gradually enriched through undulations that create a halo around the principal replying sound (0'19''; 0'29''; 0'37''; 0'44''; 0'52'').

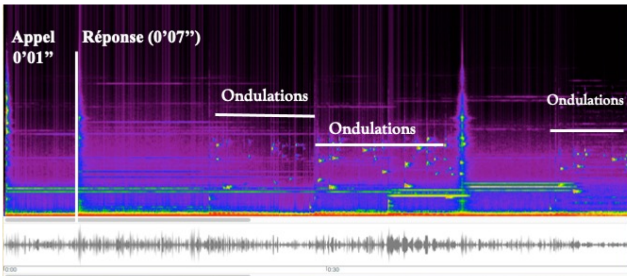

Fig. 5: In A tu memoria by Minsburg the first section of the piece (0'00''-2'22'') is built around a system of replies.

5.Audiovisual works: time passing and trans-sensorial processes

In audiovisual works, chronological time and senses of time passing can be apprehended also by eyes and by ears, through a trans-sensorial process (Chion, 2013: 137). Sounds can influence temporality in different ways, that is to say through:

- «temporal animation»: sound can change the spectator's perception, transforming it from static to moving and viceversa. «Temporal animation» plays an important role in increasing or decreasing the perception of time by listeners;
- «temporal linearization»: music gives a comprehensible logic to - apparently disordered images and disrupted actions, provoking a stabilization/normalization of time awareness;
- «directional properties»: the audio section has the property of leading towards a predefined objective, a plausible or comprehensible end.

«Directional properties», in particular, can be used to mark the starting point and the end of sections within the piece.

In considering all these three aspects, it is clear that chronological organization and time management of events are only two part of the same coin profile (Avantaggiato, 2018: 4-5).

6. One piece, different temporalities

In our research, between the extremes of «electronic music» and «electronica» (Ramsay, 2014), we have experienced a great variety of situations, ranging from pieces with their simple "grid-like" structure to pieces in which the composer experiences time in multiform ways. In M. Obst's Crystal World I-IV, for example, musical time moves at different rates and the succession of episodes and shows diverse profiles: circular, flat, accelerating or decelerating in stages, each one opens up to different temporalities and perceptual dimensions.
The special attention to different temporal domains creates a kaleidoscopic variety of perceptive plans, that become a strong point of the cycle:

- the temporal profile of attack, sustain and release of oriental percussive instruments;
- the use of scales of frequencies. The harmonic system on which Crystal World I (Fig. 1) and Quartetto III are based, demonstrates that some authors do not merely compose the sounds, but also use the "temporal" differences that separate them and act on them;
- the organization of musical discourse in textures and gestures at an intermediate level;
- the use of different psychoacoustic effects such as reverbs that allow the composer to simulate different ambiences and scenes that give an idea of contrasting temporal and spacing coordination;
- the simultaneous presence of regular distributions in the form that are accompanied by accelerating and decelerating gestures in stages (Fig.6);
- the coexistence of different arrangements of sounds over time: from motivic movement to drifting and fractional polyrhythm (Fig. 7) to regular or stochastic intermittencies (0'54'' to 2'13''; 8'21 to 8'51'': second movement Chorale); from constant slowing down to constant speeding up (0'00'' to 0'11'': 2'21 to 2'34''; 3'08'' to 3'21'': third movement); from simple to complicated repeating patterns (1'49''to 2'21''; 2'34'' to 5'06'': first movement).

The appreciation of different temporal dimensions in this musical cycle, allow us to make some considerations:

- multi-temporality allows to increase the sense of variation and musical interest for such a long work;

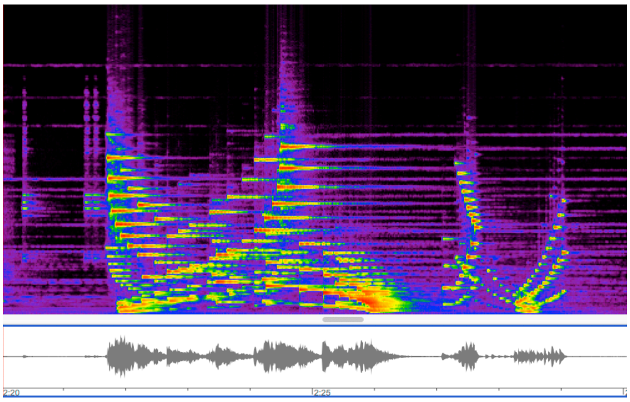

Figure 6. Interméde by M. Obst: Sonogram of the central section of the episode.

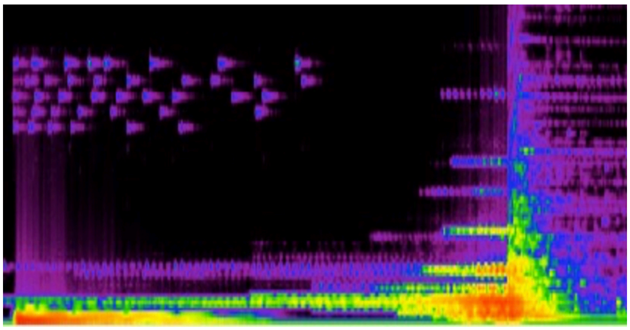

Figure 7. Crystal World I : polyrhythm with a log distribution (3'42'').

- the analytical techniques developed in the field of acousmatic music are not sufficient to accurately describe the complexity of pieces like Crystal World, which is a concentrate of different rhythmic opposites (Curtis Roads, 2015: 184).
  The piece, being rich of accelerations and decelerations with different shapes – concave, convex, logarithmic (Fig.7), seems to recall those profiles described by G. Grisey in his «continuum of rhythm» (Grisey, 1987: 239–275);
- temporalities and rhythmic dimension are the most neglected by analytic theories: in this context, we consider «rhythmic oppositions» by Roads and Grisey's «continuum of rhythm», as an important starting point for further analytical development.

7.Multiplicity of forms: some hints

Durations that make sense in music start from the threshold of timbre perception (Bregman; McAdams, 1979: 12) and go up to the macro timescale, which is commonly connected with musical form. Composers sometimes employ timescales that exceed those limits:

Durations less than the micro timescale are musically usable only as mass events; durations that last more than the threshold of human body fatigue can be experienced only in part and not as a whole (Pasoulas, 2020: 221).

At macro timescale level, the shape of an experimental electronic music piece varies from «emerging» to a rigorous controlled one.
The rigorous control of the form of a piece is typical of Structuralist period, even if not exclusive of that season.
In F. Donatoni's Quartetto III, a piece largely influenced by Structuralism, the sonographic shape is imagined «a-priori» by the composer (Fig. 8).
The shape of an inverted hourglass accidentally recalls the concept of irreversibility by Ilya Prigogine (Prigogine, 1988: 9-13), a Nobel laureate famous for his work on dissipative structures, complex systems, and precisely, irreversibility. In Quartetto III, the arrangement of the elements is specular with respect to time and sound matter. After the central pause – that divides the piece into two halves, the original series of frequencies is exposed, activating an idea of circularity of the piece and of irreversibility of time passing. At an intermediate formal level, Donatoni, instead, creates temporal shapes starting from single phrases by expansion; by contraction;

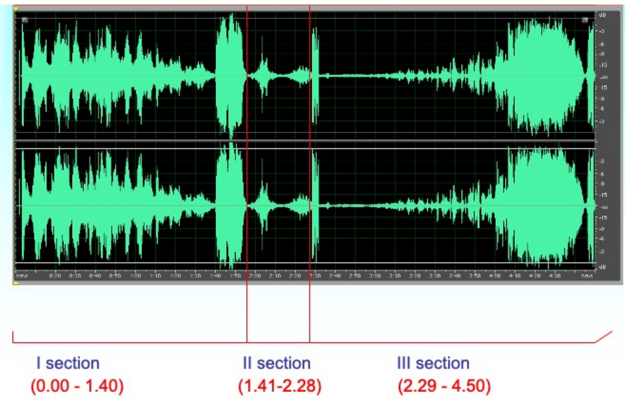

Figure 8. Quartetto III - Overall form (Avantaggiato, 2014: 10).

by selection, strategies widely described in the volume «The Musical Timespace» (Christensen, 1996: 92).
In J. Alvarez's cycle Cactus Géométries a natural perspective influences the shape of the piece: the composer chooses some of his favorite «cacti» as musical metaphors for some possible new sonic topologies.
In Spectralism, composers describe, instead, the sound object as a complex formation that can be dilated to create a formal process. Spectralists often start from the natural space - a natural, delimited «microphonic space» - to come to an «imaginary» screen, where the composition is artificially projected. Artifice and nature interact: the form reflects the depth of sound on the imaginative plane and the image acts, implicitly, from connective with which something switches from one to the other.
The presuppositions of this musical problematic are the practices of optical-acoustic conversion of sound by Emile Leipp, derived from sonographic analysis, and the philosophical conceptions by Deleuze's and Bergson's (Manfrin, 2003: 1-32).
In Landscape music, the composer sticks to an immediate description of the surrounding world: the aesthetic shadow of the world seems to prevail over the composer's subjective interpretations.
The landscape composition is also a particular genre in which, the already cited experience of the «time of being» (par. 3) becomes a central factor of time awareness.
Mathematical models have been highly influential on F. Bayle's works (Thom, 1985), as reported in the volume «Techniques d'écriture sur support» in the paragraph «G. Montage par variations catastrophe» (Vande Gorne, 2018).
Amongst the shapes described by Thom, we can mention: le pli (the fold), la fronce (the frown), la queue d'aronde (the dove tail), le papillon (the butterfly).

Conclusion

In this article we have described how management of time is something even more complex than the sheer chronological organization of events and their dislocation by recurrence, quality and quantity.
Time affects different domains with various degrees and compositional strategies may help to modulate the perception of time (Par. 3).
In Par. (4-6) we have described that the compositional activity is influenced by a multidimensional rhetoric: metaphoric relationships are operative at different levels. We've pointed out the importance of understanding musical rhetoric as an act based on sound and time that guides meanings at different levels, from sound objects to spatialization; the influence of rhetoric becomes more complex in the wider context of multimedia (Par. 5).
In Par. (6) we have reported the case of Crystal World, a cycle composed of 4 different movements, in which the coexistence of different temporalities allow us to point out how temporal and rhythmic aspects are covered by consolidated analytical techniques in a quite incomplete way. We have cited «rhythmic oppositions» by Roads and Grisey's «continuum of rhythm», as an important starting point for further analytical development.
Different and personal conceptions of time also reflect on the form of a work (Par. 7).

References here concern the musical repertoire by J. Alvarez; F. Bayle; F. Donatoni; M. Obst; F. Otondo; M. Rodrigue.
The several musical examples in this article show that authors should demonstrate to have an important ability: to work with sound and time, then, is to be present and to draw audience's attention to the present.

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