Korean Electro-Acoustic Music Society's

2021 Annual Conference

PROCEEDINGS

October 16 Saturday - 17 Sunday, Lecture Room, Platform-L

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Foreword

An-Nyeong-Ha-Se-Yo?

I welcome you all to the Korean Electro-Acoustic Music Society's 2021 Annual Conference (KEAMSAC)!

This conference, hosted by Korean Electroacoustic Music Society (KEAMS), offers precious opportunities for professional composers, scholars, and any other musicians from all around the world to share characterful and noveltious issues on electro-acoustic music. As the consequence of the conference, we publish the computer music journal *Emille* every year, embracing a wide range of discussions and creative works in the field. Since 2011, *Emille* has been expanding its scope and challenging the limit by diverse international attendees to this conference. In line with the efforts and passion of KEAMS to the event, the Seoul International Computer Music Festival (SICMF) takes place together.

I would like to express my sincere gratitude to the Art Council Korea and all authors and participants for making this conference possible. Last but not least, I would like to thank all staffs and the committee members for their hard work and strong support.

October 16, 2021

Byung-moo Lee
President of Korean Electro-Acoustic Music Society

KEAMSAC2021 TimeTable

2021.10.16 Saturday		
10:20-10:25	Kevin Parks 박케빈	Opening Greetings by Conference Chair 학회의장의 개회인사
10:30-11:30	Mara Helmuth 마라 헬무트 University of Cincinnati	[Keynote Speech] Can Computer Music Save the Earth? 컴퓨터음악이 지구를 지킬 수 있을까?
11:35-12:05	John Baxter 존 백스터 University of Miami, USA	Swimmer's Ear: Emulating Kinetic Sound Using Headphones and Sounds of Water 수영하는 사람의 귀: 헤드폰과 물소리를 사용하여 움직이는 사운드 모방하기
12:10-12:40	Daniel McKemie 다니엘 맥케미 Independent Artist, New York, USA	Dynamic Stochastic Control Voltage Generation: Adapting Iannis Xenakis' GENDY Program for Modular Synthesizer 동적 추계학의 제어 전압 생성: 이아니스 크세나키스의 젠디 프로그램을 모듈식 신서사이저로 활용하기
12:45-13:45	Lunch Break	
13:50-14:20	Daniel Corral 다니엘 코랄 University of California San Diego, USA	Polytope and other Microtonal Intermedia by Daniel Corral 다니엘 코랄의 다면체와 다른 미분적 중간매체
14:25-14:55	Ryo Ikeshiro, PerMagnus Lindborg 료 이케시로, 퍼마그너스 린드보르그 City University of Hong Kong	SoundLab and Electroacoustic Music in Hong Kong 사운드실험실과 홍콩의 전자음악
15:00-15:30	Rachel C. Walker 레이철 시. 워커 Fellow, Akademie Schloss Solitude, Germany	Beiguan and Electronics: The space in between 베이관과 전자음악: 사이의 공간
2021.10.17 Sunday		
10:30-11:00	Guillermo Pozzati 기예르모 포쟈티 Universidad Nacional de las Artes, Argentina	A System of Contexts for the Analysis of Electroacoustic Music 전자음악 분석을 위한 문맥의 시스템
11:05-11:35	Rauren McCall 로렌 맥콜 Georgia Institute of Technology	Creative Techniques and Performance Practices in a 3D 3차원에서 창조적인 기술과 연주 실제
11:40-12:10	Jacob Elkin 제이콥 엘킨 United Nations International School, USA	Constructing Extended Just-Intonation Sixth and Twelfth Tone Scales 확장된 순정률 여섯 번째와 열두번째 음열 구성하기
12:15-13:15	Lunch Break	
13:20-13:50	Sangbin Patrick Rhie 이상빈 Korea National University of Arts, Korea	About Distortion Effect: Formalization of well-known methods & Extended methods 디스토션(왜곡효과)에 대하여: 기존 방법의 체계화와 확장된 방법들을 중심으로
13:55-14:25	Patrick Gunawan Hartono, Anthony Lyons 패트릭 구나완 하토노, 안토니 라이온스 University of Melbourne, Australia	Cinematic Audiovisual Composition 영화적 시청각 작곡
14:30-15:00	Olga Krashenko 올가 크라셴코 Rimsky-Korsakov St. Petersburg State Conservatory, Russia	Transformation into Artificial Intelligence : Aesthetical Changes in the Roles of Composers and Performers with regard to the Score 인공지능으로 바꾸기: 악보와 관련한 작곡가와 연주자의 역할에서의 미학적 변화

Can Computer Music Save the Earth?

Mara Helmuth
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Proceedings of Korean Electro-Acoustic Music Society's Annual Conference (KEAMSAC20XX)
Seoul, Korea, 16-17 October 2021

A computer musician composing in the age of climate change will benefit from considering the state of the earth today, and the interaction of music and nature. I discuss a dual approach incorporating music and science in my works which are often shaped by natural sound, environmental concerns, stochastic processes and algorithms.

Keywords: computer music, electroacoustic music, nature, stochastic, algorithmic music, environmental music.

Can computer music save the earth? It might seem to be a silly question at first. How can music, an art form, save anything, except perhaps our emotional states, through peaceful or joyful engagement with sound? Does creating or listening to music have an impact beyond the personal, emotional and occasionally informative aspects? Even if music can induce a listener to be motivated to work for changes in environmental policy, would our community of listeners be large enough to implement these changes? Is there a potential for reaching out and changing minds of significant numbers of people? Whatever the answers to these questions are, the reality is, according to recent studies, that the state of the earth appears to be currently at a tipping point. Without strong actions in the near future, we are facing predictions of a hot, miserable and dangerous future.

What is the State of the Earth?

On September 28, 2021, the U.S. Fish and Wildlife Service announced that it has determined that twenty-three new species are now extinct. This includes a fish, the Scioto madtom, last seen the year I was born in my state of Ohio. U.S. Secretary of the Interior Deb Haaland comments in this report on "climate change and natural area loss pushing more and more species to the brink. (Hires 2021) While diminishing biological diversity is an indirect threat to human life, even more alarming information is found in a report released by the United Nation's Intergovernmental Panel on Climate Change in August 2021, stating that green house emissions from human activity will even in the best case scenario, continue to warm the planet for at least thirty more years, causing increased heat waves, wildfires, floods, downpours, and draughts. Global sea levels will rise for 2,000 more years. Change is happening more and more rapidly, and there is a only a narrow window in which cutting emissions could still effectively limit the most severe implications for the future. (Fountain 2021) Many of you or your children may be alive in the second half of this century, and will experience whatever we are able to accomplish in limiting climate change and preserving a habitable and beautiful environment. Without decisive action, however, catastrophic consequences will follow. I believe that those of us with the education to understand the problem must take action, listen to the scientists, and find solutions.

In Thornton Wilder's play *Our Town,* the character Emily realizes after her death, "Oh Earth, you're too wonderful for anybody to realize you. Do any human beings ever realize life while they live it – every, every minute?" While Emily was talking about moments of family experiences that humans pass through, blind to the nuances, the same is true of our relationship with nature. How else could we have come to the point of irrevocably unbalancing our own life-sustaining environment?

Technological Impact on the Environment

Manufacturing computers has a negative environmental impact from the energy and chemicals used, and those of us who use computers to create music might consider this. Finding ways to prolong the life of these tools, such using a computer for additional time could reduce this impact.

Sound has also been used in medical devices in ways that may actually be harmful. When visiting my mother in the hospital in 2012, I noticed how the machines monitoring patients' physical states tended to emit repetitive beeps that often clashed with other device's sounds. These alarms were intended to be noticeable so that the patient received better care, but the result was distressing. These beeps are generally simple on and off events, unchanging in frequency, timbre, amplitude and rhythm. I wondered how the ill could possibly relax enough to sleep well and heal, with the noise of these beeps. Recently researchers have worked to make these sounds more natural and less stressful using whistling and singing sounds. (Rueb 2019)

Nature in Arts and Music

In exploring what a computer music composer can do to promote environmental awareness and sustainable living on earth, I decided to look first at particularly interesting examples of influences of nature on the arts, and then at the relationship with nature in my own music.

Art and Music Inspired by Nature

Art inspired by nature can be found throughout the ages, in many styles, with realistic or abstract depictions of nature. An example that speaks to me is Monet's painting Rocks at Port Goulphar, Belle-Île, which exposes the colors and textures of dramatic rock structures and water of an island south of Brittany.

Figure 1. Claude Monet's Rocks at Port Goulphar, Belle-Île (1886).

Monet at various times called the views "terrifying" or "extremely beautiful" and engaged fiercely with painting them, sometimes working 14 hours per day. His statement "paint what you really see, not what you think you ought to see" (Jones 2020) are as revolutionary for sound as it was for painting. Translated into the musical world, "compose what you really hear, not what you think you ought to hear" would do away with a lot of music that never should have been written based on misconceptions, and compel the composer to authentically engage with sound. Not to disparage imaginative new concepts of music, but they must be based on listening deeply.

Frank Lloyd Wright's Falling Water house was built in 1939 over a waterfall, exhibiting the architect's approach to organic architecture. This award winning work allows the structure built for humans and nature to coexist naturally.

In music, bird songs and other natural sounds have often inspired composers. It may be that our ideas of melodic contours and even speech patterns have been influenced by earlier humans listening to bird sounds. Olivier Messiaen analyzed various bird songs in detail, and incorporated them into his ensemble work Oiseaux Exotiques (1955-56). John Cage, who was influenced by Taoism, Zen Buddhism and the Journals of Henry David Thoreau "spoke of music as a model of benign ecological relations between human beings and the natural world," His interest in silence furthered his idea of liberating sounds from abstract ideas about them, to let them exist as simply themselves. (Ingram 2006) His work Child of Tree consists of instructions to a percussionist to improvise with amplified plant materials, such as a pod from a Poiciana tree, and the spines of a cactus, which are plucked. He wrote in For The Birds, "I hope my music will help us in accepting the importance of ecology in music." Other composers include Pauline Oliveros, whose Tree/Peace for violin, cello and piano explored the life cycle of a tree. Annea Lockwood has created installation sound maps that bring various points along a river into one's listening world. John Luther Adams's The Place Where You Listen allows the geological world of Alaska to control the installation's sound and lighting. I have also taken interest in work related to nature by Frances White, Judy Klein, and the soundscapes or soundwalks of Barry Truax, R. Murray Schafer, Hildergarde Westerkamp and Leah Barclay.

Reviewing my own work since the 1980's, I found that at least half of my pieces have a direct connection to nature, and many others are influenced aesthetically by processes related in some way to natural processes. I studied Buddhism in my early years, and also have practiced Tai Ch'i Chuan intermittently since 1980. In the practice of tai chi, movements which focus the mind and body in a tranquil way are often described by natural references such as "stork spreads its wings", "needle to the bottom of the sea," and "stroking bird's tail". I have found these calming practices to increase my appreciation for the natural word, and that they facilitate finding musical insights from nature.

Nature-based Works

My dual interests in music and science lead me to electronic and computer music in the first place, and many pieces involve natural sound, sound environments or scientific concepts from nature. The pieces I have created that relate most clearly to nature are generally in one or more of four categories: 1, based on natural sound, data or images, 2, use instruments to create sound related to natural sound, 3, use algorithms that have some connection to a natural process, or 4, pieces designed as warnings against environmental problems.

Works Based on Natural Sound or Data

Nature has provided materials for many of my works.

Early electronic works include *Occurrents* (1986), an analog magnetic tape piece based on water sounds, created at the University of Illinois Experimental Music Studios. Later when I was studying for my D.M.A. at Columbia University, my brother gave me a recording of Humpback whale sounds. I digitized the sounds and created a computer music piece "Whalesong." Both of these pieces were based on recorded natural sound.

Sound 1. Excerpt of Whalesong (1989) by Mara Helmuth.

Bird sounds have inspired a number of my pieces. Charyl Kneevers (Zehfus) created a beautiful song about endangered species entitled Star Geese (1987), and I added an electronic track of geese-like sounds.

In 1997 I composed Abandoned Lake in Maine (Helmuth, 2007), a stereo fixed format piece. Traveling in Wisconsin, I found a compact disk with recorded loon sounds. Upon listening I remembered hearing these sounds as a child on family vacations in the north woods, on Whitefish Lake, near Hayward. I created the piece with loon sounds using my granular sampling programs, which I will discuss in the section on algorithms. There were four very distinct original loon sounds: the hoot, the yodel, the tremolo and the call, which is heard at the beginning of Sound 2. The call and the tremolo were most conducive to creating varied textures so I tended to experiment with processing more with these sounds. In this excerpt unprocessed natural sound is heard at the beginning and end, and altered sound is in the middle.

Sound 2. Excerpt of Abandoned Lake in Maine (1997) by Mara Helmuth.

This piece alternated between natural sound segments and processed sound. I found the transitions from natural to processed sound to be easy to manage, but the transitions from the processed sound back to natural sound had to be handled extremely carefully to avoid awkwardness. I attributed this unexpected difference in perception to aural expectations regarding natural sound. It is not unusual to hear natural sound transformed in movies, TV or other computer music pieces. Natural soundscapes might change gradually into transformed sound worlds. Returning, however, to a totally realistic sound environment in my piece required some disruption of the sense of digital media, a knock or scrape to make the abrupt change work, or a very gradual return from a processed sound into something that resembles a natural sound, to allow the listener to realign with the pure natural soundscape again. For example, I used a windy noisy transformation to easy back into the natural soundscape at the end of Sound 1. Original soundscape recordings often have several layers, such as wind noise, crickets, and loon calls, and expectations about what is in each layer and the amplitude relationships between layers, once heard, are strong. If just one layer is primarily transformed, to return to all three layers suddenly can seem jarring. Working with a return to the original soundscape after extreme alterations of natural sound can pose compositional challenges. This may point to the importance of natural sound being heard as authentic, even in a context of a computer music composition where processing can be conspicuous and necessary.

This piece was overtly political in that samples of a naturalist's voice were processed, as were some storm-like sounds, to create a climax warning of the threat to the natural environment of the loon.

Loonspace (Helmuth 2000) was created for Allen Otte and the Percussion Group Cincinnati, using the mainly the loon material from the previous piece. An algorithmic percussion score for unspecified instruments generated by a C program was interpreted by the group. The instrumentalists' convincing choices of compatible instruments and playing techniques determined the success of this piece. The acoustic instruments created bird-like sounds and other nature sounds. This piece was more a sonic environment, than a composition.

Rock Music was a sonification based on Matanuska glacier data. A geologist friend, Teresa Davis, spent much of her summer in 2004 in Alaska measuring lake sediment data. When she mentioned "grain frequencies" and other descriptions of lake sediment which sounded similar to granular synthesis parameters, I decided to map her data into some synthesis programs. The resulting project could only be called "Rock Music" and probably because the dual scientific/artistic approach, was particularly satisfying. The challenge here was to finding expressive and evocative mappings between data and sound parameters. The potential of this technique is promising for the future, with other types of data.

Works with Instruments or Voice Based on Nature

Rippling, a fully improvised work, was a piece I created in 2000 for Pauline Oliveros's Deep Listening Retreat in Haliburton Forest and Wildlife Reserve, in Ontario, Canada. This week-long series of deep listening sessions in nature involved many singers, and much of the work we did included vocal improvisation. Rippling was a score consisting of wavy, rippling lines, meant to inspire people canoeing in a lake to interact sonically to create a musical experience. Inspired by Oliveros, the work is for either musicians or non-musicians. The performance of mostly voices also included the sounds of paddles in water and boats.

The Birds: An opportunity came up in the CCM composition department to create a score for Concert Nova ensemble and the Cincinnati Ballet. Each person took one movement from *The Carnival of the Animals* by Camille Saint-Saëns, and I chose "The Birds." I analyzed various bird samples with spectrograms, attempted to notate these sounds for acoustic string and wind instruments, and wrote a short score based on these sounds with electronics.

Water Birds was a collaborative work originally created with clarinetist Rebecca Danard for clarinet, wireless sensor network system and electronics. The wireless sensor network system and music project was a collaboration with the Computer Science department at UC. The structured improvisation used infrared sensor data from the location of the performer moving onstage to turn on or off layers of spectral delays with rtcmix~ in Max. For the score I notated fragments of music that the performer can manipulate freely. Segments of the performer's performance is recorded and played back with the spectral delay. Many timing aspects are under the performer's control. After the piece was developed, we dispensed with the sensor system, and I performed the piece taking performer location into account. The pieces has been performed widely, and each performer has taken the piece in new directions, some with my fixed format electronic part resembling what the original patch creates. Several of the performers researched and added different bird calls to the piece. The most recent performance by Andrea Vos-Rochefort incorporates bird movements as well as sound, with a flute part performed by Elizabeth Darling. Allowing the performer to bring their own experience of nature into the piece augments the power of the piece.

Figure 2. Andrea Vos-Rochefort performing Water Birds, by Mara Helmuth. (video excerpt)

The butterfly has also inspired several works, although more by the symmetral shape of its body and complex movements, than its sound. Butterfly Within for flute and fixed stereo audio was a reaction to a health crisis, and expressed my mercurial mental state at that time. The thyroid is a butterfly-shaped organ within one's neck, and mine had a serious disease in 2006. The possibility of a one's life being threatened makes daily experience seem much more intense and appreciated, and the quick movements of the butterfly embodied my changing emotions. The flute lines range between the volatile and the serene. I algorithmically generated gestures and textures from sounds of physical models of gritty shakers and dense blowbottle layers in RTcmix to interact with the flute part, which is sometimes submerged, and sometimes emerging with fervor.

Butterfly mirrors is a structured improvisation for varying ensembles of acoustic instruments and live electronics. The score and electronic parts are related to those of Water Birds, but after a first performance by the Tornado Project, the piece was expanded for a larger ensemble, Esther Lamneck's New Music Ensemble at New York University. It was first performed by these 17 instrumentalists, including electric guitar, with live electronics and a special projected video of fire. The title here refers to the motivic interactions between improvising players, who might invert material in a mirror-like fashion as they hear each other play the notated fragments. The butterfly concept is again a visual idea of a symmetrical structure, here influencing melodic development and improvised lines.

A magical moment occured at the beginning of the piece, when the flutist began to improvide acoustically, and after a moment her sound was picked up by two iPads nearby held by two performers. The iPad performers moved the iPads gradually into range of the microphones, gradually beginning to send a layer of spectral delays into the sound system. When the other microphones subsequently became live, the sound from various instruments was processed by computer and expanded sound textures with more layers of the spectral delays was sent into the speaker system. Other performances by smaller ensembles have been by Ensemble Pi, SoundProof and performers at CCM. Each time I work with new instruments, especially in the lower registers, I am astounded by some of the sounds the spectral delays can create, with the extremely long delay times I prefer.

Onsen: Hot Springs (2019) for vibraphone and fixed media had several inspirations. The first was the performer, Joseph Van Hassel, who commissioned the piece. He sent me audio and video recordings of him playing on several outdoor metal scupltures at the University of North Carolina, Pembroke campus where he teaches. I used these samples in the piece, with granular sampling, convolution and other processing. The other more conceptual inspiration was from a visit to Japan, where I was able to visit Onsen, the hot springs near Tokyo. This beautiful setting, and bathing in mineral waters, rejuvenated my energy levels intensely for three days after the visit. The bubbling sounds and sensations, the shape of a bathtub with overhanging trees, and the peaceful energy of the location influenced the piece.

Figure 3. Onsen. (Photo by Akira Takaoka.)

Sound 3. Excerpt of Onsen: Hot Springs (2019) by Mara Helmuth.

Sound Environments Worldwide

My interest in working with natural sound became more urgent, as I explored other sound environments on different continents, and concern about climate change increased. Travel experiences have been a compositional inspiration for the last two decades, and many of the materials I have recorded have been in nature. I was aware of the changing cultures and climate and felt that the time frame for experiencing some aspects of nature might not be very long.

China in 1999 was the location of the International Computer Music Conference. Visiting Beijing rewakened an interest I had in Asian culture, and I resolved to return. I also met Josef Fung the conference director and director of a ensemble of traditional Chinese instrumentalists. At that point, Beijing was a sea of bicycles at big intersections, without many cars.

On sabbatical in spring of 2003, I visited several mountain parks in China and was in residence at the Sino-Nordic Arts Space (SNAS) in Beijing, directed by Fung. I recorded samples walking in three mountain parks: Hua Shan near Xi'an in Shaanxi Province, Emei Shan, near Cheng Du, one of the four Great Buddhist Mountains of China, and Huang Shan, in Anhui Province, known as China's most beautiful mountain (Figure 3). After these great walks I arrived in Shanghai, and the SARS epidemic was underway. I noticed the look of panic on the faces of people when I coughed, due to my allergies. I was advised to return home by friends, so my trip was interrupted. I was not allowed to enter Japan, the next planned visit. By the summer I was able to return to Beijing to create an installation work, Staircase of Light, in which a dancer on a stairway controls the sounds I had recorded in the parks, and their transformations. Photocells on each stair sent data into MaxMSP to play sounds. A related concert performance piece, China Prism, performed in Cincinnati., allowed the same sonic materials to be played by a dancer on a stage.

Figure 4. "Seeing is believing" view at Huang Shan. (Photo by Mara Helmuth)

I acquired a qin (or gu-qin), an ancient 7-stringed Chinese zither on this trip in China with the help of a student at the China Conservatory of Music, with which my school has an exchange. I studied this instrument around 2005 with a teacher in Pittsburgh, and I wrote several improvisatory pieces for my own performance with electronics. While these pieces are not directly inspired by nature, some of characters for techniques in traditional qin notation are based on nature images, and I found this inspiring for composition.

I returned to China in 2007 and did additional recording, this time visiting a remote Tibetan monastery in mountainous Yushu, in Qinghai province. I recorded services, monastery sounds, and purchased Tibetan instruments and other items. By the time of these later trips Beijing had changed tremendously, with some of the smaller streets no longer there, and traffic congestion with many cars was amplified.

The installation resulting from my Yushu experience was called Hidden Mountain and was presented in Beijing in audio form, in a room of SNAS with marble floors and ancient Chinese furniture. At CCM Hidden Mountain was presented in the Cohen theater with audio, video and Tibetan instruments to be manipulated by participants. They donned a scarf with an inlaid wireless sensor, and moved around the concert hall space which affected audio and video. In a darkened space defined by a Tibetan rug, a recording service was heard from a temple, in which people entered ecstatic states, playing cymbals and other temple instruments.

I also recorded in temples in Japan such as Ei Hei Ji and at Tamakura, and in Korea and still have many excellent recordings from various trips.

Uganda's Teach and Tour Sojourners organization invited me to visit in 2011 for an experience which included teaching in various situations and recording on safari in the country's parks, which are outstanding places to find wildlife. In addition to many other safari recording situations, I spent about an hour with a pride of lions on the last day in Queen Elizabeth park.

Figure 5. With a pride of lions in Uganda.

I created an installation Sounds of Uganda for the Giraffe Park hotel where I had stayed, and where Stawa University courses were taught. I also created a laptop ensemble piece *from Uganda* (2014) in MaxMSP with rtcmix~ for several performers, based on recorded sounds of birds, frogs, a river, and hippopotamuses. A video piece from safari footage in multi-channel format also exists.

In Australia in 2016 an another extraordinary sabbatical allowed me to record sound and video at the Great Barrier Reef, the Daintree Rainforest in Queensland, and at Uluru in the desert of the Northern Territory. My project was to investigate nature, the impact of humanity on the environment, and Aboriginal sustainable living, and record samples for composition projects. A sailing tour to an inner reef, boat tours to the outer reef, walks in the forest, and hiking in the dessert were a few of the opportunities to experience and record nature. Parks are co-managed by the Aboriginal people and the government, and one might see signs as the one in Fig. 6 encouraging one to enjoy the environment.

Figure 6. Still from video taken while snorkeling in the Great Barrier Reef.

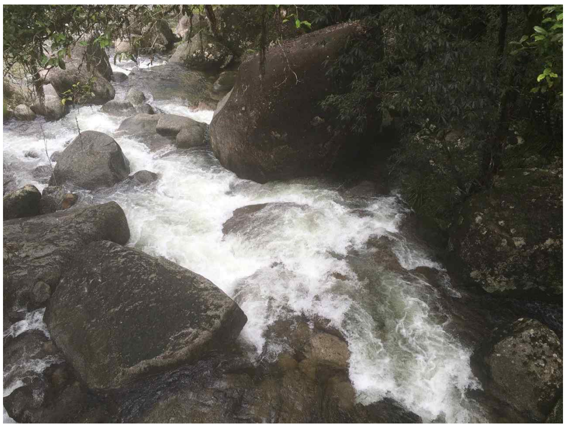


Figure 7. Mossman Gorge in the Daintree Rainforest.

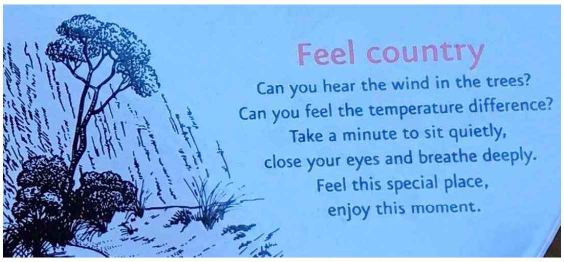


Figure 8. A sign seen on the path at Uluru, Northwest Territory.

Figure 9. Hiking in King's Canyon, Watarrka National Park, Northern Territory.

from Australia, a laptop ensemble piece with an expanded set of sounds, was one result of this unforgettable trip. In this piece there is a series of sections, which defines what categories of sounds are be drawn from. Sections are 1) water snorkeling sounds, 2), rain, 3), birds, 4), water rushing, 5) digeridoo, and 6) birds. The performer can also choose to process the sounds with RTcmix instruments for granular sampling, comb filters and a sweeping filter. An iPad, including its orientation data, may be used to control Max on the laptop. Intense listening is necessary as in any musical performance, and I advise the performers to spend periods of time listening to what others are playing, and then respond to the sounds. Processing is used sparingly to highlight the natural sound. Sharing the sounds I collected in this piece so that musicians can shape sound events together, was special way of honoring the natural sound environments and allowing others to interact with them.

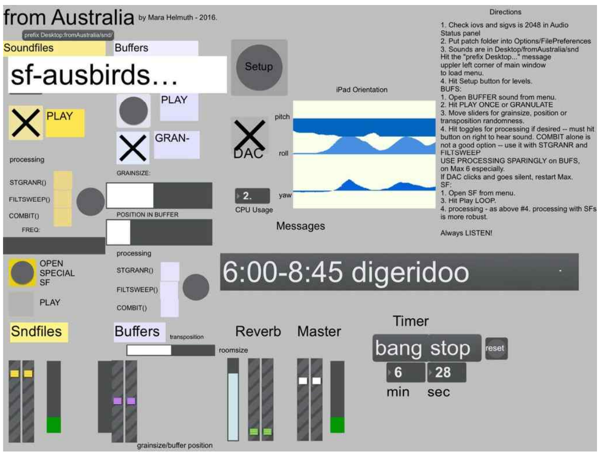


Figure 10. from Australia Max patch.

Sound 4. Excerpt of from Australia (2016) by Mara Helmuth.

After the Australia trip, I conceived of a Sonic Refuges project, with a concept of creating sonic refuge spaces for one to experience nature, or nature-influenced sonic environments.

Using Algorithms Connected to Nature

Composition micro-level and macro-level algorithms have also allowed me to create structures that have various relationships with nature.

Islands (1988) was an algorithmic piece with a C-program generated CSound score. The program created a structure of grouped frequency modulation sound events with with complex envelopes. The piece was named by Brad Garton, my teacher at Columbia, who said the sounds reminded him of islands as he drove home through the night New Jersey fog. While I had approached the composition abstractly, with a four-level logical process to generate materials of various types, the results sounded analogous to a sonification of geological formations.

Granular synthesis first caught my attention in the next year, inspired by Barry Truax's Riverrun and the formalized music of Iannis Xenakis. I created several instruments in the Cmix music programming language that would create gestural stochastic granular phrases, either by synthesis or granular sampling. The first piece I did with the synthesis instrument was called Song for Earth Day, as I found myself finishing the piece in the Columbia studio around Earth Day, 1990. While I was unable to take part in Earth Day events, I was delighted to create some natural sounding thunder and water sounds using the stochastic parameters of my new instrument. The complexity of the probability-controlled grain parameters approaches the complexity of situations in nature, such as river water rushing against uneven rocks.

Sound 5. Excerpt of Song For Earth Day (1990) by Mara Helmuth.

Extensions of these granular synthesis programs have allowed me to continue to create diverse sound worlds in many of my pieces in different genres. When processing the sounds of instruments, as well as in synthesis, the qualities of the resulting sounds are different from traditional musical phrases in that gradual changes, types of transformations and gestures tend to be more important than patterns of pitches, melodies, harmonies, or metrical structures. The timbral gestures in my granular synthesis works may have more commonalities with natural sound, even if not created from natural sound samples. This aspect may also free the music from some expectations listeners could have with instrumental music.

Environmental warning pieces include the previously mentioned Abandoned Lake in Maine with the threatening climax warning of habitat loss. All Alarms Sounding (2017) was written for two pianos and electronics. In

2016 I had spent several days snorkeling in the outer and inner reefs of the Great Barrier Reef near Port Douglas and Shute Harbour, Queensland. This reef is the world's largest organism, and full of fascinating features and fish. In the year of my visit, however, 22% of Australia's Great Barrier Reef died because the ocean temperature was too warm. A person in Queensland told me that his shoes melt on the street in summer. The sense of urgency about the degrading environmental situation triggered alarms in my mind as well as in the news. Program notes for this work read, "Alarms go off every year, every month, about the consequences of climate change…. Complex systems like the reef, the rainforest and the mangroves evolved over millenia to coexist, the wildlife in an intricate balance with their environment. Fast changes are not something that can be easily accomodated by evolution. Something may survive future climate change, but it may not be us, or life as we know it." I had resolved by this point to make environmental awareness a primary focus of my work.

Endangered Sound is a piece created for network performance using RTcmix on Internet2 for the Network Music Conference at Stony Brook University in 2018. Each performer was instructed to find sounds they considered "endangered", such as that of a threatened species. Sounds were exchanged between remote locations of CCM in Cincinnati and Stony Brook University, NY. As I have found in previous sound exchanges of this kind, the intense listening required with only audio connections, and no video, no visual cues between performers, actually enhances the improvisational experience. Performers actually had trouble finding "endangered sound" from threatened species, and I ended up providing samples. Both of the above pieces highlight threats to our environment, and my intention was to increase awareness of these issues.

Collaborations with Esther Lamneck, virtuoso performer and also a composer who has co-composed several works with me. All of these pieces have extensive use of granular synthesis algorithms which create gestural forms which are in my mind related to geological formations or the motions of wind and water. Her improvisatory and virtuosic performance is very compatible with these algorithmically generated sounds. Our first interactive work for the Hungarian tárogató wind instrument and live electronics, Irresistible Flux, was based on a old folk song. Two more recent works are more directly based on environmental ideas. Breath of Water, for clarinet and stereo fixed media was influenced by the sight and sounds of a group of humpback whales I saw on a windy boat trip from Great Barrier Reef's outer reef Opal Reef to Port Douglas, as well as Lamneck's compelling subharmonic sounds. The two sets of sounds, whales and subharmonics, had unexpected commonalities that allowed them to be connected in the piece easily.

Sound 6. Excerpt of Breath of Water (2016) by Mara Helmuth and Esther Lamneck.

Sound Dunes (Helmuth 2019), a more recent collaborative composition, is based on tárogató phrases and my digital transformations, which we realized created dune-like sound structures with curving contours and granular textures.. A new multichannel immersive version is scheduled to be premiered at the Sonorities Festival in Belfast, 2022.

Sound 7. Excerpt of Sound Dunes (2019) by Mara Helmuth and Esther Lamneck.

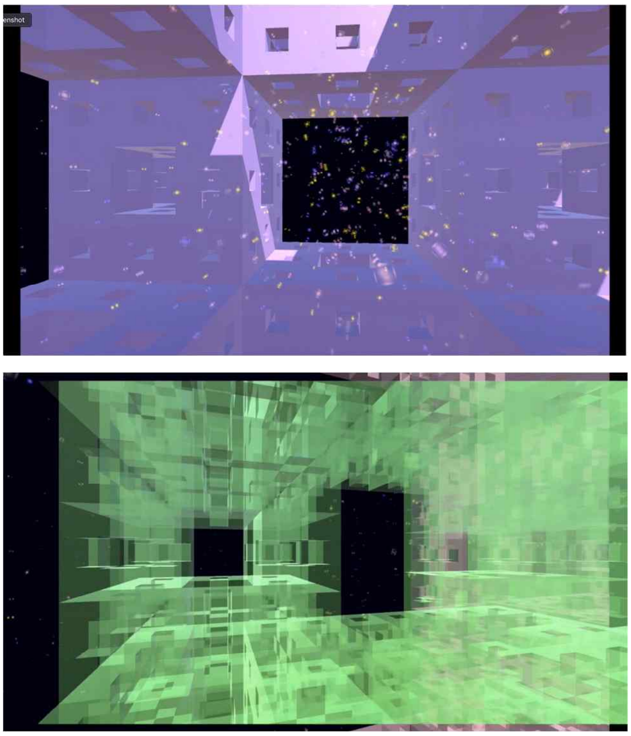
"Space" Pieces: Apart or From Nature?

Several of my compositions seem at first to be almost opposed to environmental music, coming from abtract ideas of space. Of course, space is apart from earth, but not apart from a cosmic view of nature.

Dragon of the Nebula (Helmuth 2020) was written in 1992 in response to the Gulf War, and reminded me of an image of a galactic nebula. It was composed with the same granular synthesis instrument as Song for Earth Day, but has more precisely defined granular gestures, some with "metallic" sounds (grains with long durations in dense frequency bands) or noisy granular bands. While these sounds may seem to have little to do with nature, actually the opening noisy bands of sound smoothly descending can resemble wind-like phrases, while the fierce "metallic" dragon gestures might sound related to metal percussion sounds. Many of the sounds based on probabilities rising or falling in undulating or twisting patterns, emulate the movement of water or clouds.

Expanding Space, for tuba and computer was composed for my colleague Timothy Northcut, tuba, based on a concept of the increasing space between people in the digital age, as well as the astronomical idea of expanding space. Again, while the original idea seems remote from life on earth, and the lengthy algorithmically mixed third and final section has an other-worldly feel, the acoustical realities of the magnificent F and C tubas, which were recorded in the underground CCM parking garage with a 10-second reverberation time, ground this piece in an earthly context.

Opening Spaces, which will be seen on the conference, is based on a Menger sponge fractal and realized in video with Blender and Unity. The structure is suspended in space, and becomes more complex as the viewer moves among various versions and parts of the fractal. While the idea is quite abstract, the sounds are made from RTcmix instruments based on physical models of acoustic instruments, a Helmholtz resonator (MBLOWBOTL()) usually in simple harmonic ratios, and a 2D Mesh instrument (MMESH2D()). Another aspect of the video which is influenced by nature is the particle systems which emits flecks of shininess that pass through the structure, in synchrony with the sounds. The opposition of the precisely configured abstract structure in space with the earthy quality of the original sounds, and the spontaneous movements of the particles, reminding one of snow or the fluffy wind-born seeds of trees gave me a surreal but surprisingly nurturing feeling.



Figures 11 a and b. Images from Opening Spaces (2019), by Mara Helmuth. (video excerpt – Opening Spaces)

Looking Back and Ahead

This overview of my work reveals that attention to nature has frequently brought fresh insights and materials into my music. When reaching into the natural world I have not been disappointed by the creative paths that have opened before me. I think this is because I intuitively understand how to relate to places on this earth. I am attuned to my home planet sounds, textures, skies, and bodies of water. Its life forms may seem exotic at times, but because they exist on earth, discovering them simply expands the knowledge of the story of our lives, the networks of life in each niche of each ecosystem. Each trip has broadened my knowledge and experience of not only human cultures, but the context in which humans live, the other species which they eat, fear, avoid, enjoy or revere, and the earth's structures making up the surrounding natural world.

Conservationist Rachel Carson writes in *A sense of Wonder*, "There is symbolic as well as actual beauty in the migration of the birds, the ebb and flow of the tides, the folded bud ready for the spring. There is something infinitely healing in the repeated refrains of nature – the assurance that dawn comes after night, and spring after the winter. " Humans have evolved with these ecological rhythms and their patterns provide rich materials for art.

In my work, for each new bird call sample, there are hundreds of granular processings, or other transformations, a few of which might complete an expressive family of sounds for a piece. For every stochastic process, there are countless potential tweaks of the algorithm which will expand the sound world in new directions. For some of these sounds, it will be immediately apparent how to employ them musically, while others will remain mysterious until I learn to understand their meaning, based on what I know from the natural and human-created world.

My original question, "Can Computer Music Save the Earth?" may best be answered by turning the question around: "Can the Earth Save Computer Music?" Over and over again I find I have drawn inspiration from natural sounds, data, concepts and algorithms. My most extended collaborative relationship is with nature. The sounds and scientific processes of earth inform, sustain, and enlighten me in the composing process. These practices are an opportunity for focusing collective energy toward sustaining our earth environment.

Acknowledgments. My collaborators, mentors and friends have included Brad Garton, Doug Scott, and John Gibson in the RTcmix world, Pauline Oliveros and the deep listeners, Judy Klein, and Esther Lamneck. I would like to thank my teachers, colleagues, students and my family. I am also grateful for the opportunity to share my music and ideas in this KEAMS conference. Finally I want to express my appreciation for this beautiful earth, undescribably diverse, complex and exquisitely nurturing.

References

Cage, J. (1981). *For the Birds: John Cage in Conversation with Daniel Charles*. London: Boyars.

Hires, B. (2021). U.S. Fish and Wildlife Service Proposes Delisting 23 Species from the Endangered Species Act Due to Extinction. In *U.S. Fish and Wildlife Service*.

https://www.fws.gov/news/ShowNews.cfm?ref=u.s.-fish-and-wildlife-service-proposes-delisting-23-species-from-&_ID=37017 Retrieved September 29, 2021.

Fountain, H. (2021). 5 takeaways from the major new U.N. climate report. In *New York Times.* August 9. New York. Retrieved September 28, 2021.

Helmuth, M. (2007). Abandoned Lake in Maine. In *Sound Collaborations.* CDCM computer music series 36. CRC 2903. The composer in the computer age. XI. [CD]. Baton Rouge. LA: Centaur Records.

Helmuth, M. (2001). Loonspace. In *Implements of Actuation*, EMF 023 [CD]. Electronic Music Foundation.

Helmuth, M. (2020). Dragon of the Nebula. [streaming audio]. Soundcloud audio. 8:34. Posted Dec, 2020. https://soundcloud.com/marahelmuth/dragon-of-the-nebula?si=877de992685248b0a572497206f80189

Helmuth, M. (2019). Sound Dunes. In *Sound and Video Anthology,* Women in Computer Music. 43:4. [online downloadable audio]. Cambridge, MA: MIT Press.

Ingram, D. (2006). The Clutter of the Unkempt Forest: John Cage, Music and American Environmental Thought. In *Amerikastudien/ American Studies 51*/4: 567-570. Location: Universitätsverlag WINTER Gmbh. https://www.jstor.org/stable/41158263 Retrieved October 3, 2021.

Jones, P. (2020). Monet’s Terrifying Light. In *Inside the Exhibition 846*. Chicago: Art Institute of Chicago. https://www.artic.edu/articles/846/monets-terrifying-light Retrieved September 28, 2021.

Rueb, E. (2019). To Reduce Hospital Noise, Researchers Create Alarms That Whistle and Sing. In *New York Times. July* 9, 2019. New York. Retrieved October 2, 2021.

Wilder, T. (1938). *Our Town*. New York: Coward-McCann in cooperation with S. French.

Swimmer's Ear
Emulating Kinetic Sound Using Headphones and Sounds of Water

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In searching for new interfaces between human and technology, the head and ears can often go ignored. In this project, the head of a participant was thought of as a container, able to be filled with the sounds of a material and, by tracking the movement of the head, this material can be manipulated. In this iteration of the project, the user's head was filled with sounds of water. The user could move his/her head, tilting it to the left and right, and the sound of water would behave accordingly. Uses for immersive environments and therapeutic applications are discussed.

Keywords: Kinetic, Movement, Tracking, MAX/MSP, Headphones

Introduction

Water is one of the most powerful forces on earth. Water is also very adaptable, filling any container perfectly without any wasted space. The current study focuses on the sound of water, containers, and haptic interactive feedback. Any slightly hollow object can be a vessel for water. In this study, the author created a pilot patch in MAX/MSP to allow a user to become a container for water. By experimenting with haptic interaction/proprioception, surround sound, and nature, we can continue to expand the options and technology available for re-creating environments and interaction with our surroundings.

Water is a very complex medium for sound. In Kirk's 2009 article on underwater soundscapes, he writes that, "...a natural body of water is a complex resonant space and could be reframed as an instrument in itself, just as the surface of a pond is like "a membrane enclosing something deep in thought" quoting Dunn's words in the article "Nature, Sound Art, and the Sacred" (1997).

The concept of interacting with water as the focus of a musical or artistic piece is not necessarily novel. Kirk's Argus project mentioned earlier involves allowing participants to explore interactive underwater sounds by walking near a lake body. Yonezawa (2000) allowed participants to interact with flowing water in order to create sounds and Mase (2001) expanded upon this idea. Of course, Cage's famous Water Walk also involves human interaction, directing performers to pour water into and out of vessels.

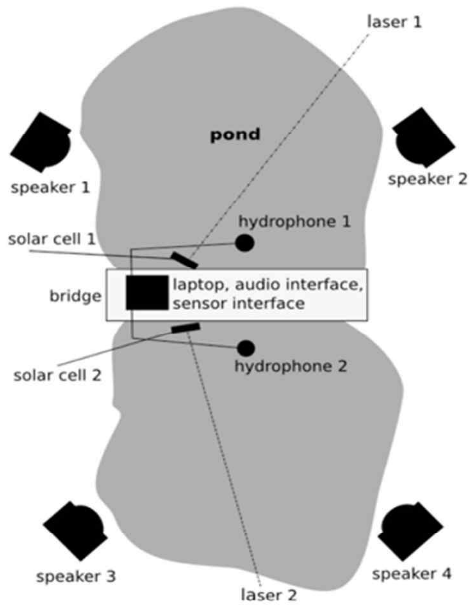

Figure 1. The design layout of *The Argus Project.*

Figure 1. Kirk's Argus Project. Hydrophones are placed underwater and send audio to speakers on the ground above.

The concept of using headphones/the head as the means of interacting with the music is slightly more novel, but not completely. Bardos (2005) introduced a concept titled Bangarama which involves a program that senses the movement of the head and creates music by, essentially, headbanging.

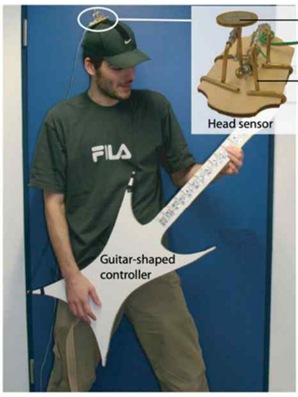

Figure 2. Bardos's Bangarama concept. In this interface, users wear a sensor on their head that will play music when the user "headbangs".

Interface/Proprioception

As Lonny Chu points out in his paper "Haptic Feedback in Computer Music Performance" (1996), the link between acoustic musicians and their instruments is often very direct and intimate. The physical link between a music artist and a computer music instrument, however, is often much less direct. This disconnect can perhaps restrict computer music artists from fully achieving the sound that they imagine. By introducing technology with the purpose of increasing the connection between performer and instrument, electronic artists can more effectively produce the music that they envision through their movements (similar to acoustic musicians).

This concept of somacoustics, a field concerning the connection between human and computer, has been researched rather extensively. Some studies reference the Japanese concept of Kansei (Camurri et al. 1999). A word with no direct English translation, the closest word in English to Kansei might be someone's aura. One goal of motion capture and somacoustics is to capture a performer's entire being and generalized pathos.

Several studies have analysed gesture and bodily movement as a medium for musical expression. However, the task of mapping complex human gestures through the use of a computer and lines of code is quite daunting. As an example, one research study uses expansion and contraction as an attribute to be studied and folded into the resultant musical expression. For instance, a person standing with their arms spread wide would, perhaps, create a larger more expansive xy field and therefore the resultant sound would be louder and more expansive. Conversely, a person in a contractive, introspective position would create a smaller, less dominating sound. This topic already shows its limitations; expansion and contraction are very generalized movements and not very connected to one's Kansei.

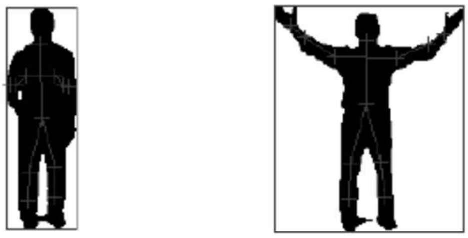

Figure 3. A diagram from Camurri et al.'s article on motion capture (2002). The figure on the right would be said to have a high contraction index while the figure on the left would have a low contraction index.

Proprioception or kinesthesia is another field of interactive studies that is very important to the current study's goal. Proprioception can be defined as awareness and focus on the body's position in space. In contrasting acoustic musicians with electronic computer musicians, Schacher (2012) claims that "Instrumental training impress the musician's body with instrumental and corporeal schemata that are guided through auditory, but also tactile, kinesthetic and proprioceptive feedback." Thus, to attempt to use the same sort of schemata in electronic music, we must create the technology to interface.

Interestingly, there is some data to support proprioceptive music/sound as an application for music therapy. In Ryan Hui's article, he claims that children with attention problems will often interact with their environment (often destructively) in order to receive much-needed stimulation (2019). Perhaps by engaging in activities involving detailed, concentrated haptic/proprioceptive feedback, children can learn to "tune in" to their body and to their inner voice, thus becoming more able to focus.

In the case of water, though, how will sound be mimicked? In many ways, sound travels much quicker and more powerfully through water than through air. So why is it so difficult to pick up on sounds when humans are submerged underwater? The normal means of transducing sounds does not work underwater due to the nature of our bodily makeup. Humans evolved for hearing sound through air using our ossicle bones bones and fleshy ear canal. However, given how much water is already within us, when an underwater audio wave comes towards us, it interacts with our ear as if it is just more water. When submerged underwater, we would not be able to hear much at all if it were not for our mastoid bone, located just behind our ear. This bone is solid; therefore, it is capable of detecting and sending along audio signals to our brain to interpret.

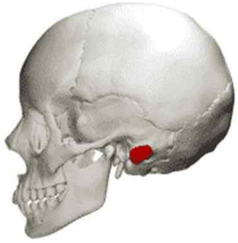

Figure 4. The mastoid bone in the human skull, responsible in large part for gathering and transporting audio signals to the brain when underwater.

Video Tracking and Accelerometers

In order to track the body and translate its movements into musical performance, the interface of motion capture is often implemented. As Bazoge et al. (2019) point out, however, the technology for advanced motion capture can often be very expensive and requires high amounts of training. In the current study, the author seeks to map the sounds of water to the movements of the users head, thus eschewing this problem.

Given the nature of the proposed interaction, an accelerometer could be implemented in order to more effectively track the vertical movements of the head. The most common use of accelerometers is in cell phones. The accelerometers in our portable devices measure the speed of gravitational acceleration on the device. They can be used, for instance, to allow our phones to mimic a steering wheel when held horizontally to play a racing game. In the current study, accelerometers were unavailable, and, as an assumption, would be unavailable to the general public as well. Thus, the author set out to create a MAX/MSP patch that would allow tracking of head movements and mapping of those movements onto a natural essence such as water and its movement as influenced by gravity.

Method

The Jitter object was used in MAX/MSP to create and capture video. For the current patch, a MacBook Pro's built-in camera was used. The Suchkah object was used in order to obtain the RGB of a clicked item in the video. For the purposes of this session, the author used colored bands that he placed on his headphones. Once the bands were captured and tracked, a formula was created to ensure an inverse relationship between the two captured bands was produced. In order for the effect of moving water to be simulated using head movements, the "water" had to flow smoothly out of one ear and into the other. Thus, when one variable increases, the other had to decrease by the same amount.

Multiple parameters were created in order to create the effect of water with the user's head as a container. To initiate the process, an audio file titled Fill was created. Users can click the Fill button after they have selected their headphones and capture their color nodes. The Fill sequence was created by recording the sound of a container being filled using a close microphone. Every recording was made with the microphone position very close to the object in order to create the impression of the sound feeling very close and intimate.

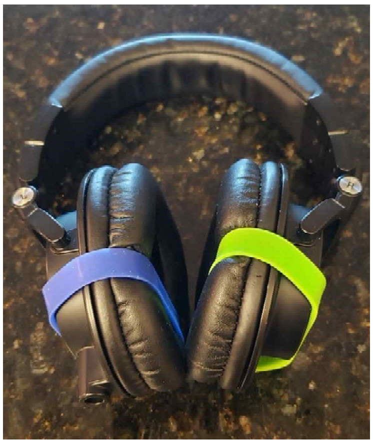

Figure 5. This image shows the bands on the author's headphones, used for capturing head movement.

While the noise of shifting water was important, perhaps more important was the background noise. A parameter titled Stay was created in order to create a constant backdrop of the sound of being underwater. Based on location of the covered bands head movement, the strength of the Stay signal will change. When there was no change in movement, the muffled underwater sound would remain in both ears at an equal level. When the head was tilted to the left, the signal would become stronger in the left ear and dissipate from the right ear (and vice versa). As a way to end the process, a sound file titled Deump was created. Dump was recorded by emptying a container full of water, again in a close setting.

Once these parameters were created, the sound files for pouring water from one container to another were created. Three files were created for right to left transfer and three files were created for left to right transfer. The files were tiered so that they would play based on minimum tilt, medium tilt, and maximum tilt. Importantly, sound files were edited once they were recorded. Using Logic Pro, the author edited the sound files to more effectively depict the underwater quality. For instance, the Fill file was automated in such a way that a low pass filter would cut more of the high harmonic range over the course of the recording. The Dump file was automated in the opposite direction, starting with very few high frequencies and ending with the entire harmonic spectrum.

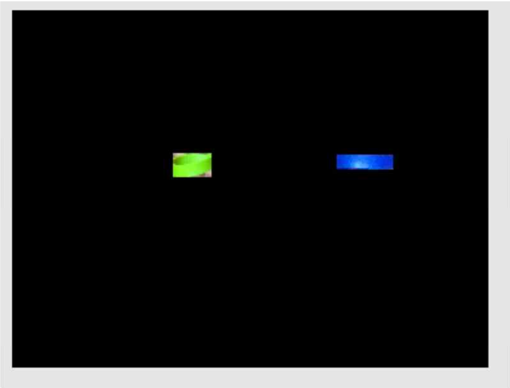

Figure 6. This image depicts the monitor within the MAX/MSP file that displays the two bands.

Once all the files were edited and exported, they were combined into a patch. After filling the container, users can tilt their heads and enjoy the sounds of water flowing between the headphones.

Discussion/Limitations

By Interacting with a program that allows people to “fill” their heads with water that can slosh back-and-forth, users can become more focused on their bodily movements and interact with a natural process through an unnatural technology. However, there are indeed several limitations to the patch. Given the fact that the laptop camera could only capture the bands when they were both in the frame, only lateral movement was captured. The camera itself had difficulties keeping track of the bands. Thus, future headphone setups could implement colored lights in order to have a stronger capture source.

Only three pour sound files were created for each tilt of the head. A greater number of sound files would have given more precision and authenticity to the sound. Water will, of course, never sound the exact same way when poured. Only one sound file was created for filling and dumping. With multiple sound files, the use of the round-robin technique would create a more convincing feeling of realism and submersion.

Future Directions/Conclusion

An apparatus of this sort has much potential for different applications. Anything that can fill a container can be imported into the program. For instance, sand, rocks, sludge, or a single rubber ball could fill the vessel. In addition to lateral movement, files could be edited and recorded in such a way as to simulate forward and backward movement, thus making use of the Z-plane. Use of accelerometers could be implemented rather than motion capture to more accurately and finely captured the tilt of the user’s head.

The question also arises of how water actually interacts with humans’ audio signal processing. As mentioned earlier, the process by which sounds are transduced while underwater is not through the normal fleshy air canal, but more so through the solid mastoid bone located just behind the ear. Generating audio through headphones, thus, is not an exact recreation.

The author felt the process of being in the program to be surprisingly therapeutic and meditative. A patch such as this could have a strong application in the field of music therapy. Magee (2006) argues that much of the reluctance or inability to integrate music technology into traditional music therapy contexts may be due to training not being available to therapists. This project might be fertile ground for future musical programs involving control and interaction within the environment.

This project could be extended to adding in sounds of the ocean with living creatures. Combined with the interactive element, this would increase the immersion/submersion. In combination with visuals from VR goggles, one could become even further immersed.

By focusing on the head as a container rather than simply a means of wearing headphones, this artistic direction can lead to a more intimate and direct method of interaction with our environment. By placing the listener in an environment they cannot usually survive in, such as underwater for extended periods of time, they can experience the world through a safe apparatus. Users can interact with powerful and dangerous forces of nature from their living room.

References

Bardos, Laszlo/ Korinek, Stefan/ Lee, Eric / Borchers, Jan. (2005). Bangarama: Creating music with headbanging. In *Proceedings of the 2005 conference on New interfaces for musical expression*: 180-183.

Bazoge, Nicolas/ Gaugne, Ronan/ Nouviale Florian/ Gouranton, Valérie/ Bossis, Bruno. (2019). Expressive potentials of motion capture in the Vis Insita musical performance. In *NIME 2019 - The International Conference on New Interfaces for Musical Expression*: 1-5. Porto Alegre, Brazil. hal02297397.

Bomba, Maros Suran/ Dahlstedt, Palle. *Somacoustics: Interactive Body-as-Instrument*.

Camurri, Antonio/ Riccardo Trocca/ Gualtiero Volpe. (2002). Interactive systems design: A KANSEI-based approach. In *Proceedings of the 2002 conference on New interfaces for musical expression*: 1-8. National University of Singapore.

Camurri, Antonio/ Hashimoto, Shuji/ Ricchetti, Matteo / Suzuki, Kenji / Trocca, Riccardo / Volpe, Gualtiero. (1999). KANSEI analysis of movement in dance/music interactive systems. In *Proc. Int. Conf. HUmanoid RObot (HURO99)*: 9-14.

Chu, Lonny. (1996). Haptic feedback in computer music performance. In *Proceedings of ICMC* 96: 57-58.

Dunn, David. (1997). Nature, sound art, and the sacred. *Music from nature. Ed. by D. Rothenberg. Terra Nova* 2(3): 61-71.

Kirk, Jonathon/ Lee Weisert. (2009). The Argus Project: Underwater Soundscape Composition with Laser-Controlled Modulation. In *NIME*: 290-292.

Magee, Wendy L. (2006). Electronic technologies in clinical music therapy: A survey of practice and attitudes. *Technology and Disability 18*(3): 139-146.

Mase, Kenji/ Tomoko Yonezawa. (2001). Body, clothes, water and toys: media towards natural music expressions with digital sounds. In *Proceedings of the 2001 conference on New interfaces for musical expression*. 1-4.

Sakaguchi, Takashi/ Kanamori, Tsutomu/ Katayose, Haruhiro/ Sato, K./ Inokuchi, S. (1996). Human motion capture by integrating gyroscopes and accelerometers. In *1996 IEEE/SICE/RSJ International Conference on Multisensor Fusion and Integration for Intelligent Systems*: 470-475. Cat. No. 96TH8242. IEEE.

Schacher, Jan C. (2012) The body in electronic music performance. In *Proceedings of the Sound and Music Computing Conference*: 194-200.

Team, by TPSMTS. (2019). Focus and Functional Proprioception through Music. *Tamara's Piano Studio & Music Therapy Services*. Retrieved from https://www.tpsmts.com/focus-and-functional-proprioception-through-music/

Yonezawa, Tomoko/ Mase, Kenji. (2000). Tangible sound: musical instrument using fluid water. Proceeding of *ICMC2000*, Berlin.

Dynamic Stochastic Control Voltage Generation: Adapting Iannis Xenakis' GENDY Program for Modular Synthesizer

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Seoul, Korea, 16-17 October 2021

A framework to use Iannis Xenakis' Génération Dynamique Stochastique (GENDY) program as a declarative and performative control voltage generator for a modular synthesizer.

Keywords: synthesis, stochastic, Xenakis, modular synthesizer, Csound, Python

Iannis Xenakis introduced the foundations of what would eventually become the GENDY (Dynamic Stochastic Synthesis / Génération Dynamique Stochastique) program in his paper *New Proposals in Microsound Structure* (Xenakis, 1992). In this paper he outlined a methodology for the implementation of stochastic processes in the construction of sonic waveforms. It was later in his essay *Dynamic Stochastic Synthesis* that these methods were placed in more concrete mathematical terms (Xenakis, 1992).

Early examples of Xenakis' use of stochastics to directly generate audio signals include his *Polytope de Cluny* (1972) and *La Légende d'Eer* (1977). He paused his research during much of the 1980s, instead focusing on instrumental works and his UPIC System (Xenakis, 1992). It was then in the 1990s that the GENDY program and concept was formalized. This ultimately led to the realization of *GENDY3* and *S. 709* which demonstrated a complete picture of stochastic processes that determined all aspects of a composition. The possibilities that are inherent in the GENDY system are vast, but for the purposes of this paper I will focus on the algorithmic construction and development of complex waveforms for the manipulation of external systems, both in real time and in fixed media.

The first example in this paper discusses a port to in Csound of the GENDY program in Csound to control the algorithm's parameters in a live setting. Given that the focus of computer music for the last two decades has centered more around live performance than fixed media, it is a suitable development in adapting this work to these modern uses.

The second example demonstrates the use of Xenakis' techniques to define musical form and emphasizes the evolution of this form over time by way of the inaudible control voltages that are generated. This process aligns more with the compositional world in which Xenakis worked: declaring parameters in advance and then running the program to sonically realize the musical result with no real time control or interference. Here, instead of treating the program's output as final, it is used as a control stencil in that the computed signals are output as voltage then patched into the modular synthesizer.

Hybrid System

These examples make use of both the computer and the modular synthesizer in one cohesive system. This combination seeks to expand the capabilities of both devices to fully maximize the possibilities of signal generation, modulation sources, and analog and digital computation in live performance (McKemie, 2021). The Hybrid System enables the computer to send control signals to the synthesizer which impacts its sonic output. Similarly, the modular synthesizer sends control signals back to the computer, informed by *and* informing the computer's actions in a quasi-recursive feedback loop. There are many options in how a Hybrid System can be configured based on user interests. More details and explanation can be found here[1].

In the same vein as *GENDY3*, the simultaneous realization of multiple tracks of the algorithm is possible (Hoffmann, 2009). Independent control over each track's parameters lends itself well to a variety of patch points of a modular synthesizer. The tracks can send either audio or control voltage (CV) signals that are derived from the mathematics of the algorithm in action and further modulated to whichever degree the end user's hardware is capable.

Figure 1. An out-of-the-box envelope follower, designed by Synthesizers.com

Inversely, the use of triggers and gates from the modular synthesizer enables time-based influence over various parameters in the algorithm, therefore expanding the feedback capabilities overall. These two directions of influence create an opportunity for the creation of an environment in which everything *can* influence anything else.

In one example, a sample and hold circuit is firing random triggers back into the computer to randomly change the parameters of a single track. This track is also acting as the source signal from which the sample and hold circuit/module grabs its values. While the computer could use its system information to provide random seeding[2], I opted instead to manually assign seed values to reproduce desirable sequences while manipulating other non-random variables. The analog white noise generator gives a unified bridge between the two systems. The speed at which the sample and hold sends a trigger is determined by the chaos level of a different track's y-axis movement. In this situation, as the amplitude distribution becomes more chaotic, the more likely it is that the sample and hold circuit will fire. The result is a self-generating feedback loop that plays itself without, at least theoretically, ever repeating. The white noise generator in the sample and hold provides what amounts to be one of the truest forms of randomness available to humans.

Adaptations of GENDY

CSound

Tito Latini ported the microsound generator portion of the GENDY program to Csound[3] as an opcode based on Nick Collins' Gendy1 ugen in SuperCollider (Collins, 2011). Within this ugen there are nine parameters:

1. Amplitude
2. Amplitude Distribution Curve
    a. Linear
    b. Cauchy
    c. Logistic
    d. Hyperbolic Cosine
    e. Arc Sine
    f. Exponential
    g. Sinusoid
3. Duration Distribution Curve
    a. (same as above Amp Distribution Curves)
4. Amplitude Distribution Range
5. Duration Distribution Range
6. Amplitude Multiplier (scale)
7. Duration Multiplier (scale)
8. Minimum Allowable Frequency of Oscillation
9. Maximum Allowable Frequency of Oscillation

Using TouchOSC (Open Sound Control)[4] on an iPad, these parameters can be manipulated in real time, providing continuous and tangible control of the algorithm while also allowing for playback at either audio or sample rate over multiple tracks. This is a tremendously powerful implementation of the technique for not only its mobile-control, but also being provided with a set of highly customizable touch components to control the algorithm in detailed ways. Figure 2 shows in Csound how OSC is wired to the GENDY opcode for live control.

```
;Dynamic Stochastic Synthesis (after ;Xenakis) OSC Receive
Snippet
instr 333
kSlider 1 init 0.0
kSlider 2 init 0.0
…
kSlider 7 init 0.0
Stext sprint "%i", $R_PORT
ihandle OSCinit $R_PORT
kAction OSClisten ihandle, "/gendyCSound", "fff",
            kSlider1,
            kSlider2,
            …
            kSlider7


;FREQ controls should never hit 0
;Params scaled for effectiveness in ;live performance
aout gendy 0.7, 0, kSlider3, kSlider4, kSlider5, kSlider1+0.01,
kSlider2+0.01, kSlider6, kSlider7
outq1 aout
endin
```

Figure 2. Code snippet of OSC control of the GENDY Csound opcode

In my piece *Dynamic Stochastic Control Voltage Generation (after Xenakis)* (McKemie, 2020), multiple tracks of this algorithm are wired into the modular synthesizer and used as control voltage (CV) and audio sources to modulate various aspects of the instrument. These include anything from oscillator frequency, filter cutoff, envelope parameters, and more. The program also receives output(s) from the modular synthesizer in the form of trigger and gate signals which are used to randomize the algorithm's parameters, thereby changing the signal output from the computer. This creates a feedback mechanism between the two halves of the system and injects the performance with an added layer of indeterminacy, pushing the player into a trinity of human – machine – computer with each providing their own unique contribution to the order.

Aesthetically, the purpose of this work was to expand upon the use of Xenakis' algorithm, all the while paying homage to the composer. It is certainly clear for those familiar with the audible characteristics of GENDY that it was not my intent to mask that quality, but rather, to embrace it as a necessary part of the work. This stands in contrast to other adaptations of the GENDY program, which have sought to either update the platform in which the program is running (Hoffmann, 2009) or to faithfully reproduce new works aligned with how Xenakis may have realized them (Doornbusch, 2002).

One of the primary tools used here to convert the audio output of the algorithm to control signals in this work is a bank of envelope followers, and my aim with the work was to see what musical opportunities might arise when they were used to control the available modules in the system. With that came the challenge of mixing seven different GENDY instances into one system to achieve a stereo output that did not devolve into constant noise. This was a particularly important point as a product of something akin to pure noise due to a failure in mixing or appropriate signal flow design would negate the purpose of this adaptation. With the goal being a continuation of the canon, I felt it important to treat the process much like a performative interpretation of GENDY, rather than a gutting of it (Di Scipio, 1998).

Python

The second case is a program written in Python to generate values from a random walk that are then translated into points of a waveform and extracted to a wave file. Unlike the previous example this approach focuses more on variability and change over time, although not in *real* time. This specific use also moves away from the parameters and mathematics found in the original GENDY algorithm to focus more on the concepts of random walks and how different arrangements of stochastic points can be used to construct a waveform.

Stochastic math is what Xenakis used to define form, content and events throughout all his oeuvre, with the GENDY program doing the same, albeit algorithmically and with synthesized audio (Xenakis, 1985). Still using multiple realizations of the algorithm as tracks as Xenakis did, this follows the same aesthetic goal of Xenakis' design of Dynamic Stochastic Synthesis as outlined in his essay. The process here is defining a range of time in seconds as audio sample rate, the number of integers calculated by the program, the bit depth of each point, and finally encoding these values to construct a waveform. A truly random distribution is heard as white noise, with the most orderly sequence being heard as a simple waveform. While he never explored the effects of sample rate changes on the algorithm, he was aware interested in it being a parameter of exploration in future work (Hoffmann, 2009).

The declaration of sample rate correlates to the distance between two points on the x-axis of the waveform, with a higher sample rate allowing for higher density and lower rates for lower density. The sample rates explored here ranged from only 10-300 samples per second. The program compiles the values and renders them to a wave file which was then placed into a DAW and sent through individual outputs in a DC-coupled audio interface. Figure 3 illustrates an example snippet of constructing a basic set of integers and encoding the waveform.

```
# Time Declaration snippet
# setup
obj = wave.open('sample.wav', 'w')
prob = [0.25, 0.75] # walk direction
start = 0
values = [start]
np.random.seed(123)
rr = np.random.poisson(1, length)
downp = rr < prob[0]
upp = rr > prob[1]

# random walk
for idownp, iupp in zip(downp, upp):
    down = idownp.any() and values[-1]       > -32767
    up = iupp.any() and values[-1] < 32767 val-
    ues.append(values[-1] – down + up)
…
# Encode waveform
for i in values:
  data = struct.pack('<h', i)
  obj.writeframesraw(data)
obj.close()
```

Figure 3. Python snippet random walk and wave encoder

In my piece *Time Declaration*, the multiple tracks produce a slowly evolving shape that unfolds over some period of time. In the development of this piece, the program was run numerous times with all tracks sharing the same starting point, but the random walk was seeded differently each time in order to produce variations in the direction of each track. To emphasize or clarify the form, some of the signals are treated as triggers. This is achieved by measuring the amplitude of the signal in relationship to a predefined threshold, and executing a trigger command each time the signal crosses this threshold. This approach is similar to the routing assignments in the Csound version. The effects of these triggers on the form of the piece can be heard in the changes to the density of events in the excitation of the spring reverb tank and digital noise bands.

Aesthetics

Striking features of *GENDY3* and *S. 709* are the wide bands of noise and aliasing, both of which are often considered undesirable in audio signals, are a prime characteristic (Serra, 1993). In both *Dynamic Stochastic Control Voltage Generation (after Xenakis)* and *Time Declaration*, leaving these artifacts intact and magnifying them where applicable, was by design as an homage to Xenakis' work. Within the discourse about the qualities and preferences between analog and digital audio, digital audio holds a special place in this series of examples. Having extensively worked with tape early in his career, Xenakis reveled in the unique characteristics and qualities that digital audio synthesis provides, and in his last two computer music works he is not shy about pushing these characteristics to new levels.

The goal here is not to simply replicate the mathematics or its results as Xenakis intended, but instead to evolve and adapt the technique in different ways. Specifically, being able to control the algorithm in real time, which was not possible in the late 1980s. This real time control yields tremendously fascinating results and the performance device itself is incredibly engaging for the performer. Furthermore, having direct live control over the characteristics and shape of an audio source on a microlevel is wholly unique even by present day standards. A modular synthesizer allows the user to sculpt audio in direct and immediate ways, all while patching the system to be self-generative should it be desired. With the combination of the modular synthesizer and real time control of the GENDY algorithm, this offers a tremendously deep level of control that moves beyond the plane of chaos and order of the algorithm alone.

Like Xenakis, there were other composers and engineers working in similar music domains that documented their work in papers, books, and manuals since at least the 1960s, and the concepts presented throughout this paper could easily be modified and applied to these works to extend beyond where they left off.

Future Work

This project currently uses the Daisy Seed board to house both the algorithm and the control signal generator. This board is capable of housing the functionality needed for the GENDY program as well as the digital to analog and analog to digital conversions at both audio and sample rate, as demonstrated above. Moving forward I intend to adapt the entire tech stack illustrated in this paper into a more-streamlined solution.

On the Python side I intend to build more of the GENDY algorithm in code and to create a standalone application to run in the command line. Furthermore, to introduce new libraries that will enable the program to be integrated with other pieces of software as well as the internet, and to explore deeper mathematical possibilities in the fields of physical modeling, artificial intelligence, and live coding.

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References

Collins, N. (2011). In *Proceedings of the Xenakis International Symposium*. London, UK. Goldsmiths, University of London.

Di Scipio, A. (1998). In Symposium *Présences de Xenakis.* Makis Solomos [Ed.] *Centre de Documentation de la Musique Contemporaine et Radio France*: 71-84. Paris, FR:

Doornbusch, P. (2002). *Corrosion. Music for Instruments, Computers, And Electronics*. CD, EMF 43. Albany, NY: Electronic Music Foundation.

Hoffmann, P. (2009). *Music Out of Nothing? A Rigourous Approach to Algorithmic Composition by Iannis Xenakis*. Dr. phil. Dissertation. Berlin, DE: Technischen Universität Berlin.

Luque, S. (2009). The Stochatic Synthesis of Iannis Xenakis. In *Leonardo Music Journal 19*: 77-84. Cambridge, MA: MIT Press

McKemie, D. (2020). *D/A /// A/D*. CD, VCR-1001. Brooklyn, NY: Voltage Control Records.

McKemie, D. (2021). *Control Surfaces: Using the Commodore 64 and Analog Synthesizer to Expand Musical Boundaries*. SEAMUS 2021 Paper/Presentation. Charlottesville, VA: University of Virginia.

Serra, M. (1993). Stochastic Composition and Stochastic Timbre. In *Perspectives of New Music 31*/1: 236-257. Princeton, NJ: Princeton University Press.

Xenakis, I. (1985). *Arts/Sciences: Alloys*. Hillsdale, NY: Pendragon Press.

Xenakis, I. (1992). *Formalized Music: Thought and Mathematics in Composition*, revised ed*.* Hillsdale, NY: Pendragon Press.

[1] toplap.org/live-coding-control-of-a-modular-synthesizer-with-chuck/

[2] docs.python.org/3/library/random.html#random.SystemRandom

[3] csounds.com/manual/html/gendyc.html

[4] hexler.net/touchosc

SoundLab and Electroacoustic Music in Hong Kong

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The paper introduces SoundLab, a 3D spatial audio research and practice unit at the School of Creative Media, City University of Hong Kong, co-directed by PerMagnus Lindborg and Ryo Ikeshiro, and serves as a progress report. It begins with a description and its objectives involving research, artwork, teaching and outreach. It then gives a brief account of the local context of electroacoustic music in Hong Kong both in academia and in independent music and art scenes to which SoundLab aims to contribute through its activities. The overview is partly based on preliminary findings from an ongoing study based on interviews with local musicians and artists. It is followed by the design of a hemispherical loudspeaker array dedicated to high spatial resolution audio, developed after consulting a number of academic institutions with comparable facilities and programmes. Details concerning the space, equipment and usage are considered. Future plans in relation to its objectives are given in closing.

Keywords: Electro-Acoustic Music, Hong Kong, SoundLab, surround sound, spatial audio, high density loudspeaker array, progress report

Spatial sound is fundamental to creative audio and music. In the past, multichannel loudspeaker configurations were confined to concert halls and research institutions. With the recent interest in spatial audio due to the resurgence of Virtual Reality formats (Lee 2020), along with the gradual establishment of Dolby Atmos-equipped home cinemas and cinema theatres, opportunities for experiencing surround sound for the general public are increasing. Hong Kong's creative industries are multifaceted and there is no lack of entrepreneurship. However, whilst there is undoubtedly growing interest, local industry and consumers as in many places around the world do not always keep abreast of artistically and technologically progressive forms such as electroacoustic music [EAM] or sound art, and further research into spatial audio perception and content creation is necessary.

SoundLab

SoundLab, funded with an ACIM (Centre for Applied Computing and Interactive Media) Fellowship and hosted at the School of Creative Media [SCM] (Creative Media Centre, City University of Hong Kong) since November 2020, is a physical laboratory space with a loudspeaker array dedicated to high spatial resolution audio. SoundLab enables and supports a range of research, artwork, and teaching activities.

The Joint Principal Investigators Dr PerMagnus Lindborg and Dr Ryo Ikeshiro are setting out six objectives through which the SoundLab will be deployed in research, artwork, teaching, and outreach.

- Design, equip, and maintain a lab space for research in spatial audio perception and design, with a physical hemispherical rig with 24 or more loudspeakers;
- Support research in spatial auditory perception, through perceptual evaluation of soundscape recordings under different reproduction conditions, including higher-order Ambisonics (Zotter & Frank 2019; Arteaga 2015);
- Support the creation of novel sonic artwork i.e. soundscape composition, multichannel electroacoustic music, spatial computer music;
- Conduct research into the use of sonification with spatial audio, in the context of both auditory display and art/music (e.g. Ikeshiro 2014; Lindborg 2018);
- Support existing SCM classes that have course components related to spatial audio (e.g. for film, installation, performance and games);
- Create a series of outreach events and concerts featuring spatial audio, to benefit SCM students, faculty, and practitioners in Hong Kong, and gain publicity and traction for the SoundLab.

The School of Creative Media, City University of Hong Kong, where SoundLab is housed is an interdisciplinary "school" which also includes computer scientists, social scientists and philosophers as well as practitioners and theorists of various art disciplines. Being in such an environment, we have consciously positioned ourselves as the "sound" faculty. Indeed, we call ourselves SoundTeam partly in order to carve out our own little niche in the mainly media-related mélange here. That is to say, for better or for worse, we are not in a dedicated music department. Yet it is a fitting environment for SoundLab, as we will see below.

EAM in Hong Kong

For historical reasons, the scene for experimental music in Hong Kong is rather different from that of neighbouring countries and large cities, in that it is quite extroverted in its interests and sources of inspiration. Nevertheless, EAM made in Hong Kong is not well known in the West (Battier & Liao 2018). Comparatively speaking, exponents of more commercially oriented genres such as EDM might be better known abroad (Charrieras 2020).

In order to research the local scene, the authors have begun interviewing musicians and artists based in Hong Kong on the topic of EAM (by which we loosely refer to musique concrète, elektronische Musik and subsequent developments) for want of a better term. What follows are partly based on preliminary findings from our ongoing study.

As is well known, EAM began life at various national-level radio broadcast stations mostly in the West, with the one notable exception being Japan (Fronzi 2015; Chadabe 1997) It subsequently took root in academic institutions, usually in a music department, often consigned to some dusty corner where noises made by artificial means were banished.

The universities

There are, of course, numerous music departments worldwide which embrace EAM with all its delights but at first glance, this does not appear to be the case in Hong Kong. Being almost comparable to a city-state, the number of universities is obviously limited, yet some of them are highly ranked internationally. Perhaps there is an insufficient number of mid- to low-ranking institutions that can allow themselves to have more progressive music departments. Such institutions may be inclined to include less traditional music in their curriculum, and opt for music technology programs that involve sound art, computer music, and EAM composition.

Despite chasing the rankings, City University of Hong Kong [CityU] could fit this profile. Although lacking a music department, the few faculty working with sound at the School of Creative Media who have come and gone, including Samson Young, Takuro Mizuta Lippit (aka DJ Sniff) and Ken Ueno, as well as its general “creative media'' environment have somehow managed to produce numerous alumni active within experimental music, or music influenced by EAM to some extent. In this respect, perhaps CityU has done more in comparison to other universities (Yiu 2021), with superior international profiles and dedicated music departments.

Dig deeper and one may also find pockets of activity at Hong Kong Baptist University [BU], Hong Kong Academy of Performing Arts [APA], the Chinese University of Hong Kong [CUHK] and Hong Kong University [HKU] among others. However, they mainly operate in relative isolation from each other and from the local scene. Instead, their efforts are directed towards international events, which are favoured in the assessment of outputs, rather than any local endeavours (Keyes 2021).

The independent scenes

Thus it is perhaps no surprise that instead of a genuine EAM scene, we find experimental and underground music scenes where one may detect the influence of EAM if one so wishes in Hong Kong (Wu 2021; Yiu 2021). Not that there are “actually existing” EAM scenes which form and grow organically anywhere, and at least some kind of an incubator in the form of an academic institution or two or more may be required. In addition, EAM even at universities may no longer be “pure EAM”: the ivory tower has gradually been breached by music from the outside world. But through a lack of a coherent scene supported by academic institutions and their music departments in Hong Kong, the most promising avenues for EAM and its extensions are Contemporary Musiking Hong Kong (contemporary music/EAM and crossover music), the Hong Kong Composers’ Guild (contemporary music with approximately one EAM concert per year), the Hong Kong New Music Ensemble (contemporary instrumental music, sometimes with EAM), soundpocket (sound art) – all supported by the Hong Kong Arts Development Council – or underground alternatives.

In order to build a community as well as to offset the financial cost of putting on shows (and one of the highest cost of living in the world), finding new audiences may be one solution. Several agree that the support of funding bodies – the Hong Kong Arts Development Council [HKADC]) is the main option (Yiu 2021) – and the use of accessible art and culture venues such as Tai Kwun (Wu 2021) or Hong Kong Arts Centre. However, support from HKADC for EAM is severely limited due to its music division not appearing to fund experimental music, with half of the aforementioned organisations receiving grants intended for supporting mixed-media art instead. There is an argument to be made against chasing grants and making EAM into a career, and remaining underground (Xr 2021).

It may be the same old story as in numerous places around the world, but it does place a greater emphasis on the responsibilities for SoundLab’s outreach programme. However, a growing tendency for nurturing the local scene has been evident in recent times (Lion 2021). Hong Kong can boast one of the world’s strictest travel restrictions in its aim of reaching the holy grail of zero locally transmitted COVID-19 infections. As a consequence, many artists from abroad have opted against visiting Hong Kong due to the requirement of a two- or three-week quarantine in a government-designated hotel. One silver lining is that the lack of international travel has promoted an increase in opportunities for local musicians and artists. Expressions of national identity have been more evident in the arts here since the 2019 pro-democracy movement, and with concerts, festivals and exhibitions focusing on Hong Kong art out of necessity (Wu 2021), now may be an opportune moment to contribute to the local scene, and to reinvent EAM for our times (Lo 2021).

A loudspeaker array for EAM

Two-year seed funding from ACIM allowed the authors to purchase a set of loudspeakers and other equipment, and to hire a part-time Research Assistant. As a research laboratory, we were allocated the Multimedia Theatre [MMT] at the Run Run Shaw Centre for Creative Media (see Figures 1–3). Scheduling is important as other departments and faculty also utilise the space some days of the week. At the point of writing, part of the loudspeaker equipment has been delivered and is ready for the first phase in the installation.

Figure 1. Ryo and two students preparing for acoustic measurements of subwoofers in MMT.

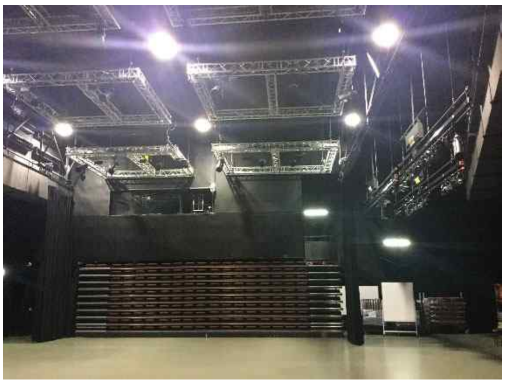

Figure 2. The space currently sports a large projection screen, truss-mounted dimmers, four curtains, and retractable seats for an audience of 150+ people.

Figure 3. The space has eight individually height-adjustable truss sections. The photo is taken during tests of a mock-up loudspeaker arrangement.

As seen in the first section of this paper, the primary objective of the Fellowship was the design and construction of a high density loudspeaker array [HDLA] dedicated to 3D spatial audio. Our first task was to carefully consider design options. We contacted experts through our network and received overwhelmingly positive interest and generous advice from some of the most experienced people in the field, both on the technical side, as well as EAM composers and pedagogues teaching spatial audio as part of their curricula. Several conversations were held in December 2020 and January 2021. In no particular order, we were in Zoom meetings with the following:

- Bill Brunson, who was instrumental in the design of Kammarsalen at the Royal Academy of Music [KMH] in Stockholm, Sweden;
- Franz Zotter and Matthias Frank, who are working at the Institute for Electronic Music [IEM], at the University for Art and Music in Graz, Austria;
- Eric Lyon and Tanner Upthegrove, who designed and are currently running the Cube (Lyon et al. 2016) at iCAT & Moss Center, Virginia Institute of Technology, USA;
- Natasha Barrett, professor in composition at the Norwegian Academy of Music [NMH] and NoTAM, Oslo, Norway;
- Simon Smith, who is currently the technical director at Birmingham Electroacoustic Sound Theatre (BEAST), UK, who was previously involved in setting up Kammarsalen at KMH with Brunson;
- Scott Wilson, who is the director of BEAST;
- Craig Jackson, who is Technical Manager at the Sonic Arts Research Centre [SARC], Queen's University Belfast, UK.

Together, they shared a wealth of information that allowed us to hone in on a suitable design for SoundLab. We weighed our Fellowship objectives against available resources in terms of funding, space, and manpower. The chosen design is a hemi-spherical array of 25 point sources in three rings, plus subwoofers; see Figures 4–5. The loudspeakers are Genelec 4030a IP on a Dante (AES67) network with PoE+ routers. The set up will be semi-permanent, allowing for flexibility and expansion of the speaker arrangement as we aim to embrace the possibilities of a design process that is ongoing and open to the evolving demands of our activities.

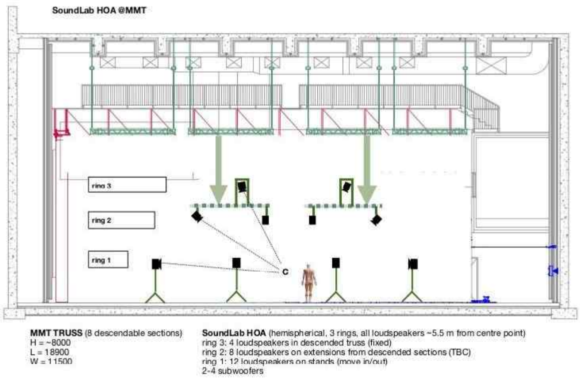

Figure 4. Side elevation of MMT with the hemi-spherical arrangement of loudspeakers (not showing subwoofers or zenith speaker).

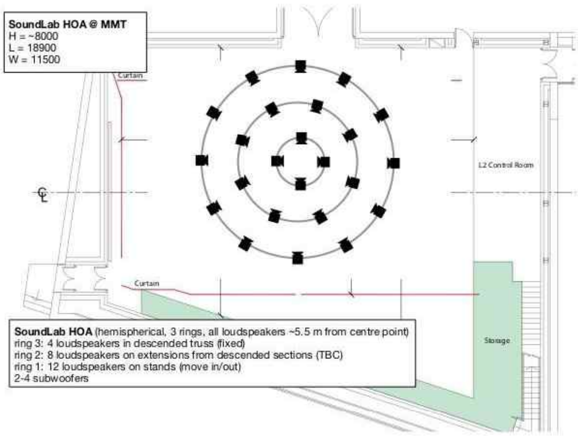

Figure 5. Top-down view of the design of the loudspeaker array (not showing subwoofers or zenith speaker).

While we had decided upon the design by mid-April 2021, purchase and delivery of loudspeakers have taken a rather long time. We enjoy good support from Genelec through Senior Technologist Tomas Lund (see e.g. Lund et al. 2019) and the company's local distributor in Hong Kong, DMT Technologies. At the time of writing, we have received delivery of 18 speakers, and foresee completing the array by February 2022.

The partial array at SoundLab will support the other objectives listed in the first section of the present paper. As for outreach events, we are organising an EAM concert with local sound artists at the end of 2021, and a student concert. In the coming year we are hosting the conference for Data Art for Climate Action (DACA 2022) and other public events, as well as conducting experimental research and composing electroacoustic music.

Follow the development of SoundLab via the website, https://soundlab.scm.cityu.edu.hk/.

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References

Arteaga, Daniel. (2015). Introduction to Ambisonics. *Escola Superior Politècnica.* Universitat Pompeu Fabra. Barcelona, Spain.

Battier, Marc/ Liao, Lin-Ni. (2018). Electronic Music in East Asia. In *The Routledge Research Companion to Electronic Music*: 49-76. Routledge.

Chadabe, J. (1997). *Electric sound: the past and promise of electronic music*. Pearson.

Charrieras, Damien. (2020). *Fractured Scenes: Underground Music-Making in Hong Kong and East Asia*. Springer Nature.

DACA. (2022). *Proceedings of 1st Conference on Data Art for Climate Action*. Hong Kong, Graz, and the Internet. January 12-15.

Fronzi, G. (2018). Aesthetics of Electroacoustic Music. In *International Lexicon of Aesthetics*. Milano, Mimesis.

Ikeshiro, Ryo. (2014). Audification and Non-Standard Synthesis in Construction in Self. *Organised Sound* 19/1: 78.

Keyes, Christopher J. (2021). Email Interview. By PerMagnus Lindborg and Ryo Ikeshiro.

Lee, Hyunkook. (2020). A Conceptual Model of Immersive Experience in Extended Reality.

Lindborg, PerMagnus. (2018). Interactive Sonification of Weather Data for the Locust Wrath, a Multimedia Dance Performance. *Leonardo* 51/5: 466-74.

Lion, Giovanni. (2021). Email Interview. By PerMagnus Lindborg and Ryo Ikeshiro.

Lo, Yun Ting Edwin. (2021). Email Interview. By PerMagnus Lindborg and Ryo Ikeshiro.

Lund, Thomas/ Aki Mäkivirta/ Siamäk Naghian. (2019). Time for Slow Listening. *Journal of the Audio Engineering Society* 67/9: 636-40.

Lyon, Eric/ Terence Caulkins/ Denis Blount/ Ivica Ico Bukvic/ Charles Nichols/ Michael Roan/ Tanner Upthegrove. (2016). Genesis of the Cube: The Design and Deployment of an Hdla-Based Performance and Research Facility. *Computer Music Journal* 40/4: 62-78.

Wu, Esther. (2021). Email Interview. By PerMagnus Lindborg and Ryo Ikeshiro.

Xr, Xper. (2021). Email Interview. By PerMagnus Lindborg and Ryo Ikeshiro.

Yiu, Siu Lung Alex. (2021). Email Interview. By PerMagnus Lindborg and Ryo Ikeshiro.

Zotter, Franz/ Matthias Frank. (2019). *Ambisonics: A Practical 3d Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality.* Springer Nature.

Beiguan and Electronics: The space in between

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Since January 2019, I have been engaged in active collaboration with Beiguan musicians at the Taipei National University of the Arts in Taiwan. This ongoing artistic research has so far resulted in a composition for Beiguan musicians and electronics, *The space in between*, which was premiered at the Kuandu Arts Festival in Taipei in September 2020. This lecture will discuss my experiences in composing electroacoustic music for traditional instruments, while considering how the materiality and rhythmic implications of Chinese language and dialects — in this case, the dialect maintained in Beiguan pronunciation, Guanhua — were treated within an electronic context programmed in Csound.

Keywords: Beiguan, Taiwan Electroacoustic Music, Guanhua, Csound.

Background to the Work

The impetus for this project came from Die Hannoversche Gesellschaft für Neue Musik (HGNM / The Hannover Society for Contemporary Music) as part of their a biannual project, TRAIECT (Traditional Asian Instruments and Electronics). My own background as a composer already includes some overlap with the study of traditional musics: I first went to Taiwan in 2014 on a research grant from the University of Cincinnati Research Council, and from 2015-2019, I was based mainly in Beijing, where I focused on studying and composing new works for Chinese instruments. The 'new' element in this project was, perhaps unusually then, not the practice of cross-cultural and cross-lingual collaboration (although, it bears saying that this is unique to each individual project, and not a static thing one arrives at), but the introduction of electronics into my work.

The compositional construction of this piece focuses on the balance between fixed and rotating mobile elements: the performers play off of individual scores, and should not view a copy of the other musician's part in performances. Both scores use modified *gongche* notation from Beiguan, which I adapted to meet the needs of the work. *Gongche* notation does not inherently specify rhythm for events. In traditional pieces, the score rather serves as a reminder, and is set to a *qupai*, or fixed melody. In these cases, the rhythm conforms to the known melody, the performance context, as well as the suggested temporality of the lyrics. In my scores, the *gongche* notation suggests the speed of recitation through the relative size of the characters according to the visual spacing within a given system, each of which represents a block of approximately 25 seconds in duration. Therefore, the exact placement of the live events between the two musicians in relation to one another and the tape, is not perfectly in sync or the exactly the same from performance to performance.

What serves as the fixed element in this piece is the electronics: there is no click track, but the tape part serves as a touchstone and also, for me, a type of aurally transmitted score, with which a fluid exchange of time with the live parts is created.

Creation of the Electronics

My process for working with electronics in this piece was three-fold:

(1) Firstly, it consisted of a collection process. I wanted to include the imprint of physical sounds in the electronics from the two places this piece was connected to: Hannover and Taipei.

Beiguan has not a singular style, but rather can be seen as an overarching category for many connected styles using different instrumental families. I was most interested to explore the more dramatic, operatic world of Beiguan, and collaborated with Taiwanese writer and interdisciplinary artist Autumn Tsai on the creation of a new text for the work connected to the story of Wang Zhaojun, a Western Han Dynasty peace token who was sent to the borderlands. This text was then adapted together with the two, musicians Liu Yu-Hsiu and Li Chi-Chien, to fit the grammatical syntax of Guanhua, the dialect whose pronunciation is preserved in Beiguan.

From the beginning, I had the idea to use Yu-Hsiu and Chi-Chien's vocalisations directly within the tape: I wanted to create a mimicking and blur between the two live performers (both of whom vocalise while playing either a plucked string instrument or a small drum) and the electronics. At the same time, I saw this as a way to decontextualise the linearity of the text — which itself is a collage across historical sources and Autumn's own narrative — by creating a dynamic transversal between the literary characters, the Beiguan voice types, and the timepoints across Autumn's script. At the collection stage, Yu-Hsiu and Chi-Chien recorded excerpts from Autumn's text using the different character and voice archetypes from Beiguan, which vary in the age and gender the performer assumes. Some of these excerpts were thus re-recorded several times, and then appear in fragmented and processed forms across the work.

At the same time, I spent several months collecting recordings from the Moog Modular Synthesizer 55 at the fmsbw Elektronisches Studio in Hannover. At this stage, I wanted to create very raw, complex, noise-based sounds, even sounds that I didn't necessarily immediately like or want, so that they could be 'mined' and altered later. I ended up with a few hundred recordings from the Moog as a result of this process.

(2) The second stage of the creation of the tape part involved 'mining' the raw materials from stage one.

With Csound, I was especially interested in creating small webs of material with cycles and random functions, so as to unwind and further explore the details and rhythms of the Guanhua vocalisations. For the voice, it was relatively easy to understand how the material would react. But, I could not necessarily predict how the Moog material would react alongside the voice recordings within some of these smaller modules, so it was, to some extent, a testing process with refining their coexistence. My goal was to carefully balance these two sound sources in the electronics, while weaving them together in a way where one would not feel a sense of displacement. In addition, I sought to create a connection between the spinning nature of the live voices with the directionality of the stereo electronics: in a performance, the two musicians are spread across the stage, while the text and material musically crosses and overlaps itself. The electronics also explore a sort of cross-hatching and instrumental distance through the use of panning.

These smaller processes I treated in a fluid way, continually adapting the code to the samples and vice versa. The exported recordings from my work with Csound were all rather short — ranging from eight to forty-five seconds — and were gathered over a period of several months.

The creation of the two *gongche* scores was done simultaneous to this stage of the process, and was also directly influenced by my earlier working process with the electronics. The idea of adding acoustic 'filters' to the live voices — asking the performers to add varying degrees of noise interference to their recitations through vocal fry and timbral coloration — grew out of my working process with the Moog.

(3) The final stage was the composition of the electronic tape itself. Although the smaller exports from Csound were left intentionally open in the mining stage, I began to adapt and categorise the material by timbral content, literary meaning and speaker, plus musical need, into a fixed version. I wished to create a sonic environment in which a 'spinning mobile' between the individual and interrelated moments both across and within the tape and the live voices would be possible.

Thoughts on Collaboration

Like myself, Yu-Hsiu and Chi-Chien were new to working with electronics. And, although they had not previously worked with living composers from outside a Taiwanese context, they had no qualms about the integration of new technology into their performances. The usage of a new text from a living writer within a Beiguan setting proved to be a more radical idea, but was one that they warmed to with time. I think that in this context, linguistic access was very important for creating an open exchange between Yu-Hsiu, Chi-Chien, Autumn, and myself.

The logistical challenges of this piece came largely from the difficulties of rehearsing across the internet due to the pandemic. *The space in between* was premiered in Taipei in September 2020, while I was in Germany. It was more difficult to hear the balance between live and electronics parts over video calls; I was also not able to be there directly in the hall to adjust the levels during the concert. I am therefore looking forward to rehearsing and hearing the piece live during a performance of TRAIECT this November at the Sprengel Museum in Hannover.

In addition to the preparations for this upcoming concert, I am continuing dialogue with the individual musicians and the Traditional Music Department at Taipei National University of the Arts. While this type of work demands a considerable investment of time and research in order to approach it in a comprehensive way, the expressive breadth of Beiguan music merits continued and detailed exploration.

A System of Contexts for the Analysis of Electroacoustic Music[1]

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In listening to electroacoustic music, different contexts intervene whose relationships determine the musical significance of the work. On the one hand, there is the context defined by the work itself, made up of all the sounds, structures, events and sound objects that are part of the piece and whose organization allows the work to be identified as such, as a unit. On the other hand, there is the context formed by all the baggage of knowledge, experiences, expectations, beliefs and assessment criteria that the listener has built or acquired prior to listening to the piece of music. The relationship between these two contexts, the one defined by the piece and the one existing in the mind of the listener, can be complex and subtle, going beyond mere referentiality. The use in the piece of elements previously known by the listener can be almost subliminal (the listener perceives familiarity with something known but is not aware of what element it is) or generate a clear expectation regarding the structural evolution of the music. Each sound object in the piece defines a sub-context within the piece, which makes it possible to distinguish what is its own and what is foreign to it. This article presents different contexts and sub-contexts involved in listening to music, explores their relationships and aspires that the ideas presented are useful as conceptual tools for the analysis of electroacoustic music.

Keywords: Electroacoustic music, system of contexts, focal pitches, analysis, reduced listening.

The core of this article is divided into three parts. The first part presents different contexts involved in listening to electroacoustic music. Their general characteristics are described and, in some cases, specific analytical tools are proposed for its study. The second part shows how these contexts interact with each other. Eight types of binary relationship between contexts are presented and phenomena arising from these relationships are examined. Finally, the third part provides additional examples that illustrate how these contexts work cooperatively functioning as a true system.

Part I: The Contexts

There are four types of context that will be considered in this paper and that are involved in listening to electroacoustic music. They are defined by:

- The inner content of individual sound objects.
- Musical segments that encompass various sound objects. These contexts will be called *local contexts*.
- The musical piece.
- The knowledge, experiences, expectations, beliefs and assessment criteria that the listener has built or acquired prior to listening to the piece of music. This context will be called *the external context*.

They will be denoted by the letters w, x, y and z, respectively. Each of them is discussed separately below.

The Inner Content of Individual Sound Objects (*w*)

Each sound object defines a context. It defines a border that separates what is part of it from what is not. This means that no matter how complex the interior context of a sound object is, it will be perceived as the internal richness of a single sound. We now present concepts that prove useful for the analysis of the interior of a sound object.

First and second order focal pitches. There are sound objects of a certain duration and complexity in which it is possible to clearly perceive one or more pitches that become the focus of attention during listening. These pitches can form true internal melodies that characterize the evolution of the sound object. They will be called first-order focal pitches. It is very useful to analyze a sound object by locating first-order focal pitches on its spectrogram. This allows a 'spectral dissection' operation that consists of separating the focal pitches on the one hand and the rest of the sound object without those focal pitches on the other. In this remainder, other focal pitches may eventually be perceived that had not been consciously initially detected. These new focal pitches, if any, will be called second order focal pitches. The concept of focal pitch can be generalized to that of focal element to encompass any characteristic of the sound object that is relatively stable and with high salience.

Internal rhythm. Perceived changes in the spectral quality of a sound object can give it an internal rhythm. A particular case is when a first-order focal pitch presents perceptually clear amplitude oscillations whose peaks (local maxima) do not exceed on average five or six per second.

Local Contexts (x)

A local context is a musical segment that encompasses various sound objects. Local contexts are organized hierarchically, the large ones encompassing the smaller ones.

The Musical Piece (*y*)

It is the context defined by the piece itself. It is made up of all the sounds, structures, events and sound objects that are part of the piece and whose organization allows the work to be identified as such, as a unit.

The External Context (*z*)

It is the context formed by all the baggage of knowledge, experiences, expectations, beliefs and aesthetic-musical assessments that the listener has built or acquired prior to listening to the piece of music. Included here is the listener's knowledge of sounds from the external world, including their causes and meanings. His or her knowledge about works, musical styles, musical composition and technological tools related to the creation of electroacoustic works also belong to this context. The listener's perceptual capacity is also part of the external context.

Previous Work on Contexts

Innumerable references to factors external to the work can be found in the literature, for example:

> In my discussion of music, I would like to use the term 'mimesis' to denote the imitation not only of nature but also of aspects of human culture not usually associated directly with musical material. (Emmerson, 1986)

The existence and usefulness for the analysis of contexts of type w and x also has antecedents in the literature. See Smalley's distinction between texture-carried and gesture-carried. Even the term context is used in the following quote:

> ... we can refer to the context as gesture-carried or texture-carried. (Smalley, 1997)

In relation to the transition from one type of context to the other, Smalley uses the expression

> We seem to cross a blurred border... (Smalley, 1997)

This leads us to the next section.

Borders between Contexts

There are sound events that inhabit a border area between contexts of type *w* and type *x*. Between one type of context and another there is a diffuse zone, of transition. It is possible for example that certain events are halfway between roughness and fast iteration. In other words, between a context *w* (a sound object with rough quality) and a context *x* (that presents in rapid repetition a version without roughness of that same sound object). This transition zone is related to the way perception processes acoustic changes at different time scales. Its musical importance is echoed in the following statement by K. Stockhausen.

> Thus the transition from one time-area to another causes a change in our perception of phases. This observation could form the basis of a new morphology of musical time. (Stockhausen, 1959)

A musical example that exploits this transition zone is presented in the third part of this paper.

Contexts and Time Scales

C. Roads (2001) lists nine time scales. There is a correlation between the contexts of type *y* and *z* with the *macro-* and *supra-time scales*, respectively. Likewise, it is tempting to relate contexts of type *w* and *x* with the *sound object time scale* and the *meso time scale*. However, a context of type *w* is defined more by qualitative factors rather than quantitative / temporal issues. The defining quality of type *w* is that it is texture-carried, in Smalley's terms. A three-minute drone is a *w*-type context, and a half-second melodic gesture, made up of three pitches in rapid succession, will define a type *x* context as long as the listener hears that there is more than one sound in that unit.

Contexts and Musical Entities

Many relationships involving sound objects and local contexts (R_{ww}, R_{wx}, and R_{xx}) can be based on the same common nucleus. That nucleus can be a sound, a spectral quality, a succession of pitches, etc. The different variants around this nucleus will be perceived as different facets of the same entity (and not as different entities). The contexts involved in these relationships are the 'stage' where an entity is presented from multiple perspectives. Each recontextualization of the nucleus gives rise to a new experience that adds to the previous ones to favor a deeper understanding. Each new perspective reveals a particular manifestation of something more general. A geometric analogy seems pertinent. A cube viewed from the front looks like a square. If you look at it from another perspective, you can see other faces. The experience offered by each new angle of observation is integrated with the previous ones and deepens the understanding of the object of perception. The different experiences are not associated with different entities but with different facets of the same entity. The third part of this paper presents a detailed example of an interval (C-G) that through successive recontextualizations leads to diverse musical meanings. It will also be seen that each pitch of this interval tells a different story, C changing its spectral quality and G crossing the boundary that leads from roughness to iteration, that is, it crosses the dividing line between contexts of type *w* and contexts of type *x*.

Part II: The Eight Types of Intercontextual Binary Relationship

In this section, eight types of binary relationship between contexts will be derived. For this, it is necessary to know the type and quantity of contexts that a piece of music can have. Usually a piece presents several sound objects. Each of them defines a context of type w. Sound objects are integrated into larger, hierarchically organized units. These units define contexts of type x. It is evident then that there are many contexts of type w and type x in the same piece of music. Rather, there is a single context of type y and a single context of type z for each particular listener (the piece itself and the background of that listener, respectively). Each type of context is related to others of the same type, in case there is more than one context of that type, and also to each of the other three types of context. This creates eight fundamental types of relationship between contexts: R_{ww}, R_{wx}, R_{wy}, R_{wz}, R_{xx}, R_{xy}, R_{xz}, R_{yz}.

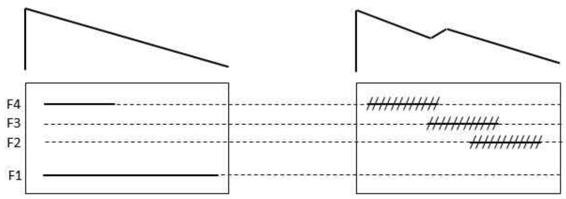

Figure 1. Diagram of some relationships between two sound objects taken from Base Metals, by D. Smalley.

Relation R_{ww}

Any relationship between two sound objects is a relationship of type Rww. The relationship between two sound objects can be complex and reveal the potential information that the second object generates by 'reinterpreting' focal elements of the first object. By way of illustration, it is useful to compare the first sound object of the work Base Metals, by Dennis Smalley, with another sound object of the same piece that begins at 3' 05''. The first object has two first-order focal pitches, the frequencies of which are indicated as F1 and F4 in Figure 1. The second object has F4, but not F1. The retained focal pitch that was perceived clean in the beginning is now affected by roughness by the presence of spectral energy at frequencies adjacent to F4 and followed by other first-order focal pitches of frequencies F3 and F2 that altogether originate a true internal melody. The top part of the figure also shows the amplitude envelopes of both sound objects. Later in this paper it will be shown how these envelopes, among other factors, influence in different ways the relation of these sounds with the external context.

Relation R_{wx}

Any relationship between a sound object and a local context is a relationship of type Rwx. The nature of the Rwx relationship determines whether a sound object is integrated with others in a single gesture or if it contrasts with what surrounds it thus acquiring a particular relief. The study of Rwx also allows us to better understand the different types of interaction that can occur between the interior of a sound object and what is outside it. Two types of interaction between a sound object and a local context are examined below, which will be called combination rhythm and projection, respectively.

Combination rhythm. It is a particular type of interaction between a sound object and its own local context. It combines the traditional notion of rhythm with that of the 'internal rhythm' of sound. The traditional notion of rhythm assumes a relationship between two or more different sounds. An isolated sound is not in itself a rhythm. To be part of a rhythm that sound needs to 'connect' with others. Rhythm is a phenomenon 'external' to individual sounds. In electroacoustic music, on the other hand, it is also common to find sounds that have an 'internal rhythm'. The combination rhythm is that formed by the combination of the internal rhythm of a sound object with the external rhythm that it forms with the sounds that surround it. B. Parmegiani made a graphic transcription of his composition De natura sonorum. At time 1 '44'' of the first Étude (Incidences / résonances) this transcription symbolically reflects four consecutive sound objects. At the top of Figure 2 are the symbols used by Parmegiani for these sounds. The letters A, B, C and D are not part of the original transcription but have been added here to identify the four sound objects in this fragment. The last one (D) has an internal rhythm that interacts with the external rhythm defined by the preceding sounds. The internal rhythm of D is reflected in the spectrogram.

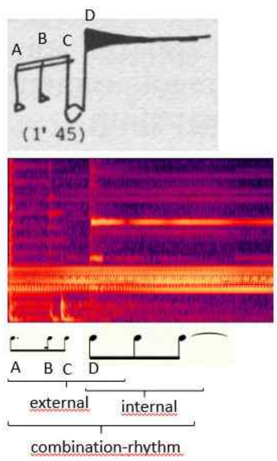

Figure 2. Combination rhythm formed by the interaction between external rhythm and internal rhythm.

Projection. This type of interaction takes place between a sound object and a local context, which may or may not be the same one in which said sound object is presented. The fundamental idea is that there are relationships that originate between different elements of a local context that can be 'projected' inside a sound object. In other words, the internal life of a sound object reflects processes that take place outside of it. Something that happens in a context of type x is projected onto one of type w. Consider for example two consecutive vowel sounds, instances of the phonemes / u / and / a /. It is possible to project the relationship between these two sounds into a single sound object, whose internal life is based on the continuous transformation that leads from one to the other. The beginning of the Étude Élastique, by B. Parmegiani, provides an example (Fig. 3).

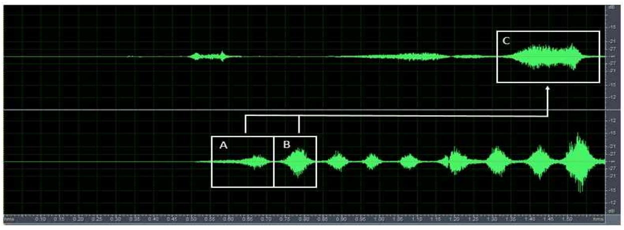

Figure 3. Projection of the sequence A-B inside C

The sequence of sounds A and B in the right channel is projected shortly after to the left channel inside sound C.

Relation R_{wy}

This relationship takes the whole of the piece as the environment of a particular sound object and analyzes how the context of type w defined by this particular sound object is related to everything that happens in the piece. It is here where the extraordinary potential characteristics of this sound object emerge with respect to all the others present in the analyzed composition. The first movement of G. Ligeti's chamber concerto for 13 instrumentalists presents an exceptional event consisting of a long ‘E flat’, tenuto, pp, senza vibrato that sounds in five octaves. In the context of the piece, this event marks a before and after. On the contrary, the pronunciation of the letter 'C' in the composition entitled ABC by P. Lansky, is a salient event only at the level of its own local context, since it is the only vowel sound that is heard in about half a minute. However, considering the complete piece it is clearly seen that it is one more vowel sound among many other vowel sounds that appear when pronouncing other letters of the alphabet. We will return to this piece in Part III.

Relation R_{xx}

Local contexts are organized hierarchically, the large ones encompassing the smaller ones. R_{xx} is the relationship between two local contexts, of the same or different structural level. When the related local contexts belong to different structural level, R_{xx} can reveal interesting phenomena, for example that a small local context summarizes what happens in another of a higher level. Just as a local context can be projected inside a sound object, a local context can be projected onto a lower level one. This idea of projecting the large into the small is at the heart of fractality.

Relation R_{xy}

This relationship allows to have the complete panorama of the structure. The piece shows the relative temporal position of each local context, which defines its formal function in the whole (exposition, development, 'reprise', etc.).

Relations R_{wz} , R_{xz} y R_{yz}

These relationships originate the phenomena of quotes, referentiality and evocation. Also the different listening modes enunciated by different authors are determined by the nature of these relationships. For example, attenuating or eliminating (if this were possible) the relation R_{wz}, that is, the relation between a sound object and the external context, leads to the concept of reduced listening by P. Schaeffer. On the contrary, in D. Smalley's so-called technological listening, we have that the relations R_{wz}, R_{xz} and R_{yz} displace the others:

> Technological listening occurs when a listener ‘perceives’ the technology or technique behind the music rather than the music itself, perhaps to such an extent that true musical meaning is blocked. (Smalley, 1997)

The 'invasive' role of the external context is clear. The 'blocking' of musical significance mentioned by Smalley in his quote coincides with the idea that the three relations discussed here can displace the internal relations R_{ww}, Rwx, R_{wy}, R_{xx} and R_{xy}. In other words, the relationships that involve the external context are imposed on the others in a particular and excessive way. The system of contexts is an analysis tool and accounts for this scenario without condemning it, admitting it as one more way of 'listening' among other possible ones. For Smalley, however, this situation does not lead to "true musical significance".

The R_{wz} relationship of each of the sound objects represented in Figure 1 reveals that the first of them has a high referential power to a bell-like sound. The second, on the other hand, does not refer to the external context with the same force due to its amplitude envelope and the roughness of the focal pitches, among other factors. At most it can be interpreted as a 'sonic metaphor' for a bell-like sound.

Any observation regarding the style of a piece of music involves examining a R_{yz}-type relationship.

The *z* context of the composer. A case of particular interest is that of the composer, who during the composition of the work has probably heard the sounds of his piece dozens of times, both separately and in different combinations, always carefully and critically examining its constructive and functional potential. The final version of a sound object may be the latest in a series of refinements on previous versions. The composer will be able to identify the sounds with which he worked even when they are part of complex textures. Obviously, the rest of the listeners, who have not had the experience of listening repeatedly and separately to the sound objects, will perceive the music in a different way from that of the composer. The context z of the listeners is very different from that of the composer. The composer often assumes that what he or she hears is similar to what the audience of his or her piece hears in the first place. The composer's context z has unique peculiarities, so it is not possible to expect a high intersubjective correlation between this context with the z contexts of other listeners.

Part III: Additional Examples

This section presents concrete examples of how the system of contexts operates in electroacoustic works.

ABC by Paul Lansky.

The listener's expectations system can be activated through the use of 'cultural objects' external to the work, objects that the listener knows and whose sequential structure allows predicting its normal continuation. For example the alphabet (a, b, c, d, etc ...) or the natural numbers ordered from least to greatest (1, 2, 3, 4, etc ...). The piece *ABC* by P. Lansky provides a clear example. After having heard the sounds corresponding to 'a', 'b', 'c', ... the listener expects ... 'd', and then ... 'e'. The internal context of the piece favors this tendency, making the time distance between one letter pronunciation and the next always the same. In the absence of temporal regularity, the predictive power generated by the alphabet alone is weakened. It is the mutual cooperation between the external context and the internal context that arouses the emergence of expectation regarding the appearance of the next letter pronunciation. This analysis is an example of a R_{yz}-type relationship. As an example of a relationship of the type R_{wx}, consider for example the sound object that corresponds to the letter 'C' and its local context. In the sound object a noise component and a downward pitch inflection are perceived successively. There are no other vowel sounds in the vicinity (the previous one occurred 16 seconds before and the next will come after 16 seconds). In this way, the local context contributes to the local salience of the sound of the 'C', allowing the memory to record it firmly. Significantly the downward pitch inflection of the sound object lands on the pedal note that is sounding from the very beginning of the piece. This agreement between the last part of a sound object with its local context of getting the same note gives rise to a subtle effect of resolution.

Break Up by Jorge Rapp.

The first CD of electroacoustic music edited in Argentina includes the work *Break Up* by Jorge Rapp. The piece reaches a climax and, after a brief silence, allows to hear an applause, which creates the impression that the work is applauding itself, thus usurping the role of the audience. This is a particular case of a R_{xz} relationship.

Smalltalk by Paul Lansky.

The work *Smalltalk*, by Paul Lansky, conveys the most subtle nuances and inflections of the human voice in the context of a conversation. However, the only thing that the composer leaves hidden at the beginning of the piece is, precisely, the vocal timbre; instead uses a plucked string sound. At a given moment, almost in a ghostly way, the voice is glimpsed for very short moments and deep in the background, as if it were revealing its presence from a hiding place, which leads to a retrospective resignification that allows us to understand that the voices were there from the very beginning of the piece, but the awareness of this does not occur until later. This phenomenon shows that the relationship of a musical piece with an element of the external context may be different from the explicit quote or reference.

Chopin by Guillermo Pozzati

The piece uses piano sounds to quote passages from Chopin's waltz Op. 64 No. 2 and also uses human voices to pronounce the name of the aforementioned composer in French. The listener who knows Chopin and his work then connects on the cognitive plane sounds as different as that of a piano and that of the human voice. The unit is then supplied by the relations with the external context (relations of the type R_{wz} and R_{xz}) and not by internal relations.

El Sendero de Cristal by Guillermo Pozzati

The following analytical comments are based on the stereo version of this piece[2]. Figure 4 shows the content of the left channel at the very beginning of the work. It is a local context, x, which encompasses two lower-level local contexts, x_1 and x_2, both have a common nucleus, the succession of pitches C-G. x_2 provides a new perspective in time with respect to x_1, it shows that the separation in time between C and G can be greater than at x_1. In other words, after C, G may take longer to appear. Resignifications such as the one described occur in local contexts whose duration and complexity is compatible with the capacity of the listener's short-term memory. When x_2 starts, features of x_1 are in short-term memory and in this way perceptual data can be integrated and give rise to new meanings.

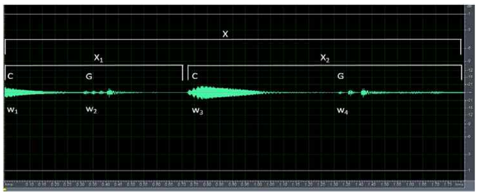

Figure 4. Two local contexts with a common nucleus, C-G. The separation time between the two pitches is longer at x_2 than at x_1.

The spectrogram of x_1 is shown in Figure 5. It reveals oscillations in the spectral energy of G that are perceived as roughness. While R_{w1z} shows referentiality to piano sound, R_{w2z} is weaker in that sense, roughness weakens referentiality to piano.

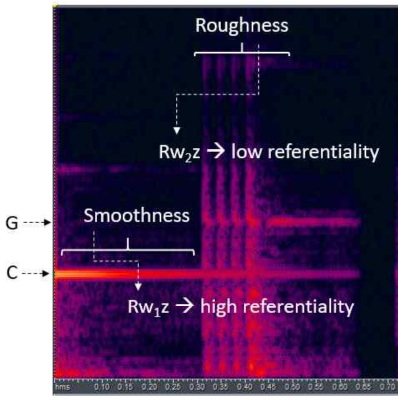

Figure 5. Spectrogram of x1.

This passage has been analyzed as the sequence of two sound objects, the first based on a C with a piano sound and the second based on a G with a rough quality. Actually C does not disappear when G enters, which can be seen in the spectrogram, but the preeminence of the latter justifies the analysis.

Figure 6 shows a higher-level local context of approximately 16 seconds duration that encompasses the previously analyzed context x. The succession of pitches C-G that x presented from two different perspectives, is presented in this longer segment from multiple perspectives. One of them, boxed in the figure, occurs a little more than two seconds later in the right channel. The information supplied is multiple, the 'C' is rough (the referentiality to the piano sound is weakened), the G is crossing the border that goes from roughness to the fast iteration (the referentiality to the piano sound is strengthened) and, finally, a pitch F that had been clearly heard a moment before appears sandwiched between the two base pitches.

Each note tells its own story. G moves from *pianissimo* to *fortissimo*, from roughness to rapid iteration and delays its appearances until it disappears. In Figure 6 eight occurrences of this pitch are indicated. In the right channel, at time 6.4s, G crosses the boundary that divides the roughness of the iteration. This is the last appearance of G in this segment that constitutes the first section of the piece. Here G acquires a new harmonic meaning by the influence of the preceding B flat. On the right channel, beginning at time 11.1s, two sound objects are heard. In the figure they are indicated with the horizontal curly bracket (2). The first presents a B flat and the second an F, but the internal life of this last sound allows the previous B flat to be heard fleetingly. When comparing this process with the one indicated with the curly bracket (1) - which includes the previously analyzed example of F inserted between C and G - it is seen that in both cases there is an isolated pitch that reappears immediately subordinate to others (or another) different. The difference lies in the way they reappear, while F reappears as an independent sound object, B flat reappears instead as part of the internal life of a single sound object. Figure 7 schematically shows the aforementioned difference.

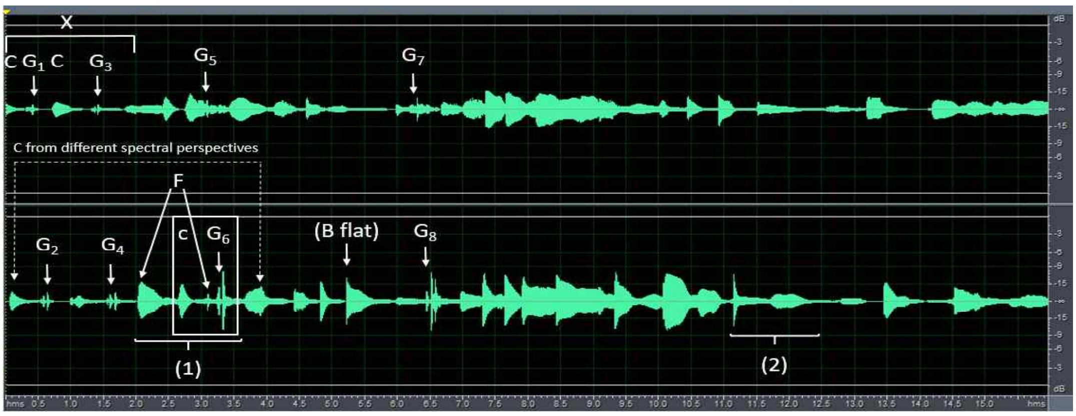

Figure 6. First section of the piece

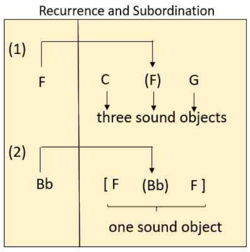

Figure 7. Two cases of recurrence with subordination of the same pitch.

C, for its part, is presented from different spectral perspectives. Compare in the right channel the two occurrences of C indicated in Figure 6 with a dotted arrow. The second C has a lot of energy above 4000Hz. This relatively high level of spectral energy above 4000Hz is a recurring phenomenon in the first seconds of the right channel whose spectrogram is shown in Figure 8.

Clearly audible energy peaks are shown with rectangles. The second rectangle corresponds to the second C just mentioned.

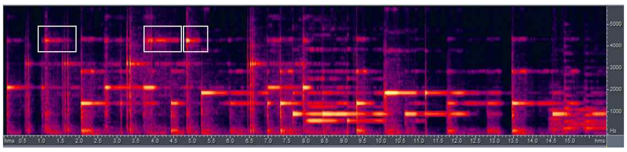

Figure 8. Spectral energy peaks above 4000Hz in the right channel.

Finally, a relationship between this first section and the end of the piece is analyzed. The work ends with a sound object lasting more than 20 seconds. The main notes of both sections together form a diatonic network. In the beginning the notes are mostly parts of different sound objects. In the end, the notes form the inner life of the sound. They characterize layers of a texture that constitutes the very fabric of the final sound object. This is an example of R_{wx}, where the time scale of the sound object is the same as that of the local context.

Conclusions

This paper has presented a system of contexts relevant for musical perception and examples that suggest how this system can be used in the analysis of electroacoustic music. Perhaps the greatest utility of the presented approach is that it offers a unified view of concepts and terms as disparate as *section*, *reduced listening*, *fractality*, *sound*, *musical piece*, *style*, etc. The ideas presented in this work can also be of benefit to the composer since they do not imply any imposition of technical or aesthetic restrictions. The system of contexts will always be operating, regardless of whether the composer is aware of it. Knowing the interactions of this system invites us to explore its concrete possibilities musically, always with the freedom that art supposes.

References

Emmerson, Samuel. (1986). The Relation of Language to Materials. In Emmerson, S. *The Language of Electroacoustic Music*: 17. London, Macmillan Press Ltd.

Roads, C. (2001). *Microsound*. The MIT Press.

Smalley, Dennis (1997). Spectromorphology: explaining sound-shapes. In *Organised Sound* (2/2): 107-126. Cambridge University Press.

Stockhausen, Karlheinz (1959). ... how time passes... In *Die Reihe* 3. English translation. Theodore Presser Co./Universal Edition.

[1] Sound examples accompanying this paper available for free download at https://drive.google.com/drive/folders/1eO20QJu9jsvOUKxeudmnS5-Mvei9AhgF?usp=sharing or by contacting the author.

[2] Originally composed in 3rd. order Ambisonics and rendered for a 24-channel hemisphere.

Constructing Extended Just-Intonation Sixth and Twelfth-Tone Scales

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To guide musicians and composers toward a deeper understanding of microtonal harmonic function, a whole number ratio is assigned to each interval in a given EDO scale. By following similar guidelines by which 5-limit JI intervals are tuned, more complex intervals can be associated and grouped revealing possibilities for their musical function. Using Tenney Height as an indication of each intervals' relative consonance, a 13-limit sixth-tone scale and a 19-limit twelfth-tone scale are constructed. The harmonic patterns translate to 36TET and 72TET respectively. Analysis of the relative interval complexity, O/Utonality, prime limit, consonant reciprocity and chord construction are discussed. The application of scales constructed through these methods is analyzed in the first movement of Jacob Elkin's *String Quartet in 13-limit Harmony* recorded by the Ligeti String Quartet based in London, UK.

Keywords: Just-Intonation, Tenney Height

Establishing a guideline Just-Intonation ratio for each interval of an EDO scale beyond 12 has several benefits for music theorists, composers and musicians. Most importantly, It allows for meaningful comparison with 5-limit intervals in a 12-TET scale. Drawing comparisons with music which has been established for centuries could suggest new associations with microtonal harmonies and melodies. Given the infinite nature of microtonality (the infinite possible divisions of the octave,) limitations are useful for a more complete comprehension. In addition, in the same way Just-Intonation enhances a musicians interpretation of 12-TET music through 5-limit ratios, higher limit ratios may help musicians to interpret microtonal music of different divisions of the octave.

When constructing Just-Intonation scales for comparison with 12-TET 5-limit harmony, it is logical to follow guidelines which maintain a level of similarity between systems. To this end, one ratio per interval is chosen when possible. The ratios chosen should also maintain the lowest prime limit possible to achieve all intervals in order to achieve maximum consonance. They should approximate the EDO intervals as closely as possible within the limit chosen. There should be a similar level of symmetry through the use of reciprocals as the generally accepted 5-limit intervals. Finally, maximum consonance (lowest complexity) should be maintained. Figure 1 illustrates these characteristics in 5-limit JI intervals.

Ratios allow for several measurements of interval complexity. *Benedetti height* is the product of the numerator and denominator of a ratio reduced to its lowest terms or the least common multiple. Named after mathematician and music theorist Giovanni Battista Benedetti, it was first proposed as a measure of inharmonicity. [1] The logarithm base 2 of *Benedetti height* is the *Tenney height*. Named after composer and music theorist James Tenney, the *Tenney height* provides the same information as the *Benedetti height* with smaller numbers for easier comparison. A larger *Tenney height* value will mean a more complex interval while a smaller value will be associated with a less complex interval. This measurement of interval complexity is important for deciding between intervals which are very close in relative consonance.

The main comparisons between 5-limit 12-EDO intervals and microtonal scales are tonality, prime limit and *Tenney height.* The 5-limit 12-TET Just-Intonation intervals have an equal distribution of overtone to undertone ratios around the point of symmetry of the tritone. For example, the major seventh, most commonly tuned to 15/8 is an overtone ratio which is the reciprocal of 16/15, the ratio for a minor second. The minor second is adjusted by the same cents derivation as the major seventh and is represented as an undertone. The prime limit shows the highest prime number multiple in a given ratio. A higher prime limit ratio will often be a more complex interval except when the numerator and denominator are higher value integers. The term "5-limit" means that a given scale only uses ratios with a prime limit of 5 or lower. The *Tenney height* for these intervals gives expected values of an octave as the simplest ratio, followed by the perfect fifth, perfect fourth, major sixth, major third, minor third etc. These will provide context for microtonal intervals.

Ratio	Cents	Tonality	Limit	Tenney Height
1/1	0.00	X	1	0.0000
16/15	111.73	U	5	7.9069

Ratio	Cents	Tonality	Limit	Tenney Height
9/8	203.91	O	3	6.1699
6/5	315.64	U	5	4.9069
5/4	386.31	O	5	4.3219
4/3	498.05	U	3	3.5850
45/32	590.22	O	5	10.4919
3/2	701.96	O	3	2.5850
8/5	813.69	U	5	5.3219
5/3	884.36	O	5	3.9069
16/9	996.09	U	3	7.1699
15/8	1088.27	O	5	6.9069
2/1	1200.00	X	2	1.0000

Figure 1. 5-limit Just-Intonation 12-TET

By using the criteria explained above as guidelines, further divisions of the octave can be assigned suitable ratios. A sixth-tone scale (36-TET) can be constructed by choosing 13-limit ratios in order to achieve accurate approximations of the sixth-tone intervals. Two tritone intervals are given as a dual point of symmetry. They may be interchangeable in practice and both are included only for the sake of completeness. There is an equal number of overtone and undertone ratios. These ratios not only reveal relationships between intervals, but through *Tenney height* measurement, give a clear indication of relative consonance. These relationships can be useful for analysis even in EDO settings. Intervals which previously may not have shown a clear relationship, can be seen to be related through their ratios. For example, the intervals of a sixth flat major third, a sixth sharp major second, the minor second and unison (16/13, 16/14 (8/7), 16/15 and 16/16 (1/1)) form an Utonality, revealing their relationship in the subharmonic series. [2] A similar relationship is shown in their reciprocals, giving insight to harmonic function which is not immediately obvious in a standard 36-EDO.

Ratio	Cents	Tenney Height	Limit	Tonality
1/1	0.00	0.0000	1	X
50/49	34.98	11.2586	7	U
26/25	67.9	9.3443	13	O
16/15	111.73	7.9069	5	U
13/12	138.57	7.2854	13	O
11/10	165.00	6.7814	11	O
9/8	203.91	6.1699	3	O
8/7	231.17	5.8074	7	U
7/6	266.87	5.3923	7	O
6/5	315.64	4.9069	5	U
40/33	333.04	10.3663	11	U
16/13	359.47	7.7004	13	U
5/4	386.31	4.3219	5	O
9/7	435.08	5.9772	7	U
21/16	470.78	8.3923	7	O
4/3	498.05	3.5850	3	U
15/11	536.95	7.3663	11	U
18/13	563.38	7.8704	13	U
7/5	582.51	5.1293	7	O
10/7	617.49	6.1293	7	U
13/9	636.62	6.8704	13	O
22/15	663.05	8.3663	11	O
3/2	701.96	2.5850	3	O
32/21	729.22	9.3923	7	U
14/9	764.92	6.9773	7	O
8/5	813.69	5.3219	5	U
13/8	840.53	6.7004	13	O
33/20	866.96	9.3663	11	O
5/3	884.36	3.9069	5	O
12/7	933.13	6.3923	7	U
7/4	968.83	4.8074	7	O
16/9	996.09	7.1699	3	U
20/11	1034.996	7.7814	11	U
24/13	1061.43	8.2854	13	U
15/8	1088.27	6.9069	5	O
25/13	1132.10	8.3443	13	U
49/25	1165.02	10.2586	7	O
2/1	1200.00	1.0000	2	X

Figure 2. 13-limit Just-Intonation 36-TET [3]

Tenney height provides further context for possible interval use. *Figure* 3 shows sixth-tone ratios up to the tritone in ascending *Tenney height* demonstrating the relative consonance of each interval. Notably, the 7/5 tritone is considerably more consonant than the 45/32 tritone of 5-limit harmony and is even more consonant than the major second 9/8. *Tenney height* plays a vital role in pitch selection. There are many intervals which are very closely related and for clarity's sake, only one is selected. For example, in the case of the sixth step, 50/49 is the selected ratio instead of 49/48. Although 49/48 has a lower *Tenney height* value of 11.1997, compared to 50/49 with a value of 11.2586, the reciprocal of 49/48, 96/49, has a much higher *Tenney height* value than the reciprocal of 50/49. Therefore, for this system which uses reciprocal intervals, 50/49 is the selection with a lower overall complexity. A similar process of comparative complexity was used for selecting all ratios. These complexity comparisons may guide composers and musicians toward a more balanced perspective of 36-TET intervals in melodic and harmonic analysis. In some cases, a ratio with a lower overall *Tenney* height value may be further from the corresponding EDO interval in cents than is desirable. This is the case with 9/8 major second (about 4 cents difference) compared with the 10/9 major second (about 18 cents difference.) In this way, the selection of a single ratio per interval is often a compromise.

Ratio	Cents	Tenney Height
1/1	0.00	0.0000
4/3	498.05	3.585
5/4	386.31	4.3219
6/5	315.64	4.9069
7/5	582.51	5.1293
7/6	266.87	5.3923
8/7	231.17	5.8074
9/7	435.08	5.9772
9/8	203.91	6.1699
11/10	165.00	6.7814
13/12	138.57	7.2854
15/11	536.95	7.3663
16/13	359.47	7.7004
18/13	563.38	7.8704
16/15	111.73	7.9069
21/16	470.78	8.3923
26/25	67.9	9.3443
40/33	333.04	10.3663
50/49	34.98	11.2586

Figure 3. 13-limit Just-Intonation 36-TET intervals to the tritone in ascending Tenney height order.

While these ratios serve as valuable guidelines for a 36-TET scale, there are a number of closely related intervals which may serve harmonic purposes as supplements. For example, 13/12 (138.57 cents) is chosen as the sixth sharp half step instead of 14/13 (128.30 cents.) 13/12 has a *Tenney height* value of 7.2854 while 14/13 has a value of 7.5078. However, in combination with another interval such as 14/9, 14/13 will have a lower combined *Tenney height* value (calculated by taking the log base 2 of the multiplied least common multiple of all intervals) due to the shared 7-limit between the two intervals. A similar phenomenon occurs in the 5-limit 12-TET scale with the major second interval. While 9/8 (203.91 cents) has a *Tenney height* value of 6.1699 and 10/9 (182.40 cents) has a value of 6.4918, in combination with the minor third (6/5,) the 10/9 major second is more consonant. For this reason, it may be useful to consider supplemental ratios for a more complete harmonic analysis.

A 72-TET (twelfth-tone) scale requires 19-limit ratios for close approximations through Just-Intonation. This allows for much more accurate derivations, especially around the tritone with an adjustment of just three cents. An equal division of overtone and undertone ratios are used as well as a diverse spread of prime limits. Note that by accepting the twelfth-tone as a separate interval, many of the gaps created by JI intervals such as the major and minor thirds are filled in to approximate intervals heard in 12 EDO. These are much closer to what is heard on a keyboard instrument.

Ratio	Cents	Tonality	Limit	Tenney Height
1/1	0	X	1	0.0000
96/95	18.13	U	19	13.1548
50/49	34.98	U	7	11.2586
34/33	51.68	O	17	10.1319
26/25	67.9	O	13	9.3443

Ratio	Cents	Tonality	Limit	Tenney Height
21/20	84.47	O	7	8.7142
17/16	104.96	O	17	8.0875
16/15	111.73	U	5	7.9069
13/12	138.57	O	13	7.2854
12/11	150.64	U	11	7.0444
11/10	165.0	O	11	6.7814
10/9	182.40	O	5	6.4919
9/8	203.91	O	3	6.1699
17/15	216.69	O	17	7.9944
8/7	231.17	U	7	5.8074
15/13	247.74	U	13	7.6073
7/6	266.87	O	7	5.3923
20/17	281.36	U	17	8.4094
19/16	297.51	O	19	8.2479
6/5	315.64	U	5	4.9069
17/14	336.13	O	17	7.8948
11/9	347.41	O	11	6.6294
21/17	365.83	U	17	8.4798
5/4	386.31	O	5	4.3219
24/19	404.44	U	19	8.8329
14/11	417.51	U	11	7.2668
9/7	435.08	U	7	5.9772
13/10	454.21	O	13	7.0224
17/13	464.43	O	17	7.7879
45/34	485.29	U	17	10.5793
4/3	498.05	U	3	3.5850
35/26	514.61	U	13	9.8297
15/11	536.95	U	11	7.3663
11/8	551.32	O	11	6.4594
18/13	563.38	U	13	7.8704
7/5	582.51	O	7	5.1293
24/17	597.00	U	17	8.6724
17/12	603.00	O	17	7.6724
10/7	617.49	U	7	6.1293
13/9	636.62	O	13	6.8704

Ratio	Cents	Tonality	Limit	Tenney Height
16/11	648.68	U	11	7.4594
22/15	663.05	O	11	8.3663
52/35	685.39	O	13	10.8297
3/2	701.96	O	3	2.5850
68/45	714.73	O	17	11.5793
26/17	735.57	U	17	8.7879
20/13	745.79	U	13	8.0224
14/9	764.92	O	7	6.9773
11/7	782.49	O	11	6.2668
19/12	795.56	O	19	7.8329
8/5	813.69	U	5	5.3219
34/21	834.18	O	17	9.4798
18/11	852.59	U	11	7.6294
28/17	863.87	U	17	8.8948
5/3	884.36	O	5	3.9069
32/19	902.49	U	19	9.2479
17/10	918.64	O	17	7.4094
12/7	933.13	U	7	6.3923
26/15	952.26	O	13	8.6073
7/4	968.83	O	7	4.8074
30/17	983.31	U	17	8.9944
16/9	996.09	U	3	7.1699
9/5	1017.6	U	5	5.4919
20/11	1035.00	U	11	7.7814
11/6	1049.36	O	11	6.0444
24/13	1061.43	U	13	8.2854
15/8	1088.27	O	5	6.9069
32/17	1095.05	U	17	9.0875
40/21	1115.53	U	7	9.7142
25/13	1132.1	U	13	8.3443
33/17	1148.32	U	17	9.1319
49/25	1165.02	O	7	10.2586
95/48	1181.87	O	19	12.1548
2/1	1200.00	X	2	1.0000

Figure 4. 19-limit Just-Intonation 72-TET intervals

The application of these intervals in a harmonic context which includes 5-limit harmony requires further investigation of traditional scales. The major scale uses a majority of overtone intervals with only one undertone interval in the perfect fourth. In contrast, the natural minor scale uses a majority of undertone intervals with only two overtone intervals in the major second and perfect fifth. This duality, which has defined tonal music for hundreds of years, can be grafted onto microtonal music with the conversion of EDO to ratio approximations.

Major scale	Cents	Tonality	Minor scale	Cents	Tonality
1/1	0.00	X	1/1	0.00	X
9/8	203.91	O	9/8	203.91	O
5/4	386.31	O	6/5	315.64	U
4/3	498.05	U	4/3	498.05	U
3/2	701.96	O	3/2	701.96	O
5/3	884.36	O	8/5	813.69	U
15/8	1088.27	O	16/9	996.09	U
2/1	1200.00	X	2/1	1200.00	X

Figure 5. 5-limit major and minor scales

In *String Quartet in 13-limit Harmony*, harmonies are constructed based on scales which imitate 5-limit harmony. By choosing intervals which share common prime limits and which prioritize either undertone or overtone series, new microtonal scales are constructed. Figure 6 shows a newly created 13-limit sixth-tone microtonal duality related to "major" and "minor" of 5-limit harmony. By replicating the overtone and undertone prevalent alternating structures and maintaining a relationship between prime limit intervals, the functionality of 5-limit harmony can be applied to higher limit microtonal harmony.

C key center	Ratio	Tonality	Bb key center	Ratio	Tonality
C	1/1	X	Bb	1/1	X
Db sixth sharp	14/13	U	C	9/8	O
D quarter sharp	15/13	U	Db sixth sharp	63/52	O
E quarter sharp	13/10	O	Eb twelfth sharp	35/26	U
F	4/3	U	E quarter sharp	11/8	O
G quarter sharp	20/13	U	F	3/2	O
Ab sixth sharp	13/8	O	G quarter sharp	26/15	O
Bb	16/9	U	Ab sixth sharp	20/11	U
B sixth sharp	25/13	U			

Figure 6. microtonal scales used in *String Quartet in 13-limit Harmony*

Figure 7 shows the ratios and relative consonance of chords used in *String Quartet in 13-limit Harmony* opening measures with simplified roman numeral analysis in the key of C. Figure 8 shows the notation of these chords with the indication of approximations of the microtonal intonation. The relative consonance of the I chord to the differing IV chords is maintained while altering the intonation heavily and providing alternate emotional qualities. The subtle effect of microtonally adjusted familiar chord progressions are explored in this work.

I chord	IV chord	IV+ chord	iv chord
1/1	1/1	1/1	1/1
13/10	3/2	3/2	3/2
20/13	25/13	25/13	6/5
25/13	5/4	15/13	64/33
15/13	11/8	14/11	26/15
Tenney Height 11.9293	Tenney Height 16.3886	Tenney Height 17.1960	Tenney Height 17.0667

Figure 7. Opening chords of *String Quartet in 13-limit harmony and relative consonance*

Figure 8. Opening chords of *String Quartet in 13-limit Harmony*

Figure 9. Reduction of mm. 57-58

Figure 10. Reduction of mm.73-74

Figures 9 and 10 show piano reductions of alternate microtonal V-I cadences used in *String Quartet in 13-limit Harmony.* Despite stretching the definition of both the I and V chord, the feeling of strong resolution is maintained in both cases. Figure 9 uses the C key center scale from Figure 6 with G and A twelfth flat as borrowed tones. Figure 10 uses the Bb key center scale. Microtonal intervals expand the possibilities of such cadences to allow for movement between microtonal keys as well as shifts into traditional 5-limit tonal centers.

The exploration of scales constructed using whole number ratios may reveal new approaches to chord progression and melodic theory which extends beyond Just-Intonation to EDO scales. Relationships between intervals become increasingly complex as microtonal divisions are added. A deep look at the relative complexity, prime limit, and O/Utonality provides new context for microtonal intervals and comparison with established 5-limit harmonies.

References

Gann, Kyle. (1998). *Anatomy of an Octave*, Retrieved from https://www.kylegann.com/Octave.html

Partch, Harry. (1949). *Genesis of a Music.* New York: Da Capo Press.

Xenharmonic. (2016). *Benedetti Height*. Retrieved from https://en.xen.wiki/w/Benedetti_height

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1 Xenharmonic Wiki Benedetti Height https://en.xen.wiki/w/Benedetti_height

2 Partch *Genesis of a Music* p. 75

3 Kyle Gann Anatomy of an Octave https://www.kylegann.com/Octave.html

디스토션에 관하여:
기존 방법들의 체계화와 확장된 방법들을 중심으로

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There are variety of ways to distort audio signal which means to create certain system to add massive high-frequency noise to original signal. Well-known distortion methods of distortion include clipping, using transfer function of specific shape(like hyperbolic tangent, rational function, sigmoid function), sample & hold, signal rounding. Each method's spectral result can be formalized by experiment giving sinewave as input and defined using some mathematic formulas. Then, extended method for distortion is being suggested and they will require noisy or time-variant random value transfer function, frequency modulation with complex tone or damage signal by piercing the random-length hole to the audio signal. These methods can be classified into several categories such as making discontinuities in sample value(amplitude), keeping a constant sample value in time-domain for certain duration, ...etc.

주제어: Distortion, DSP, Effector, transfer function

어떤 시스템에 신호를 입력한 후의 결과가 원래의 것과 다르다면, 넓은 의미에서는 이것을 "왜곡된 신호(distorted signal)"라고 칭할 수 있다. 이 정의를 따른다면, 오디오 신호에는 매우 다양한 왜곡의 방법들이 존재한다. 다양한 차단 특성을 가지는 필터는 물론이고, 주파수에 따른 위상만이 바뀌는 전역통과 필터(all-pass filter)를 통과하는 것조차 왜곡이라 할 수 있으며, 입력 신호에 노이즈가 끼는 현상도 일종의 왜곡으로 간주할 수 있을 것이다.

그러나 본 연구에서는 범위를 조금 축소하여, 이른바 "디스토션(distortion) 이펙터"로 흔히 불리고 있는 다양한 신호 왜곡 시스템들을 다루어 볼 것이다. 흔히 전기 기타의 이펙터와 같은 형태로 자주 접해 보았을 법한 이 시스템에 대한 정의를 우선 간단하게 하고 넘어가려 한다.

디스토션의 정의

기성 음향 용어집이나 백과사전 등에서는 디스토션을 간단하게는 "신호가 어그러지는 현상", 혹은 "허용범위 초과로 인해 생기는 클리핑 노이즈(clipping noise)"[1] 내지는 "비 선형적 변환(non-linear transformation)"[2] 혹은 "입출력 신호의 파형이 서로 유연한 곡선으로 교차하지 않는 현상"[3] 등으로 정의하고 있다. 그러나 이 정의들은 지칭하고 있는 시스템의 범위가 지나치게 넓거나, 현재 통용되고 있는 디스토션 시스템 중 극히 일부만을 포괄할 뿐이라 본 연구의 범위를 설정해 줄 만한 정확한 정의로 쓰기엔 다소 부족하다. 이에, 아래에 디스토션을 새롭게 정의해 보았다.

> 신호를 조작하여 표본(sample)의 지속이나 클릭을 다량으로 입력신호의 파형에 만들어 주는 것, 내지는 그에 준하는 정도의 큰 표본값의 변화를 유도해 원래 없거나 적던 비중의 고배음을 증대시키되, 청취 결과상 입력신호의 기음 성분을 없애지 않는 신호변환법

먼저 위의 정의에 부합하는 기존의 여러 디스토션 방법들에 대해 알아보자. 이들은 총 네 가지의 카테고리로 나눠질 수 있으며, 각각 파형 절취법, 전달함수법, 표본지속법, 반올림법으로 명명해 보았다. 앞으로 등장할 모든 시스템의 구현은 pure data의 파생형 버전인 purr-data를 통해 이루어졌다.

기존 디스토션의 방법들

파형절취법

첫 번째로 소개할 디스토션 시스템은 파형절취법(clipping method)이다. 아래는 파형절취를 수행하는 주요 부분을 구현해 놓은 패치(patch)이다.

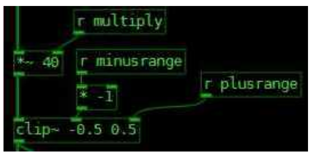


그림 1. purr-data로 설계된 파형절취 패치.

입력 신호를 그대로 n배 증폭한 이후, 일정 표본값의 범위를 설정한 후, 그 범위를 벗어나는 표본값들을 모두 평탄화해 버리는 방법으로, 가장 간단한 방법이다. 위의 패치에서는 입력 신호를 40배 곱한 후 –0.5에서 0.5까지의 표본값들을 온전히 취하고 나머지의 범위에 해당하는 표본값들은 경계값들로 평탄화하는 것이다.

위 시스템에 정현파를 입력신호로 넣는다면 진폭이 입력 신호에 비해 절반인 거의 사각파에 가까운 파형이 나오게 될 것이다. 시스템의 출력을 스펙트로그램 상에서 관찰해 보자.


그림 2. 440Hz의 정현파를 파형절취한 결과의 스펙트럼.

예상대로 사각파의 스펙트럼과 매우 유사하다. 전 대역에서 홀수 번째의 배음들이 두드러지며 그 외의 위신호 현상(aliasing)에 의해 발생한 주파수 성분들도 전 대역에 걸쳐서 고르게 조금씩 관찰된다.

이 시스템에서 조작할 수 있는 변수는 두 가지다. 입력 신호를 얼마나 증폭할 것인가를 의미하는 증폭도(amplification factor)와 어느 범위의 표본값을 취할지를 정하는 절취 범위(clipping range)가 그것이다. 이 두 변수들을 적절히 취하지 못한다면, 절취되어 본래의 표본값이 변형되는 범위 속에 들어오는 표본들의 개수가 적어서 충분히 디스토션이 일어나지 못하여 효과적이지 못한 결과를 얻게 된다. 그 예로 정현파를 입력 신호로 넣고 증폭도를 1.2로 설정하고 절취 범위를 –0.8~0.7로 설정했을 때의 실험결과를 아래에 보인다.

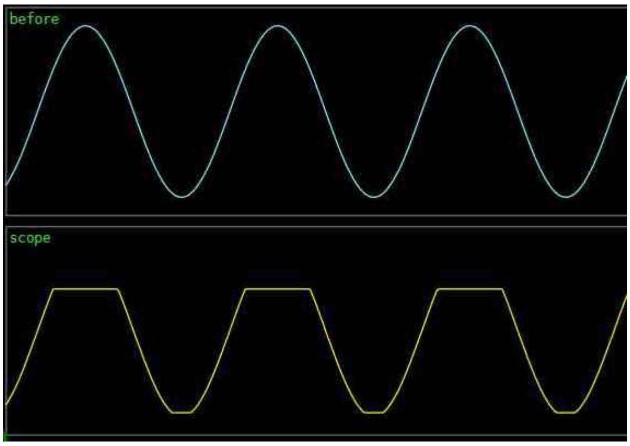


그림 3. 효과적이지 못한 변수들의 설정으로 인한 결과.

파형절취 패치에 정현파만을 입력신호로 넣었을 때에는 비교적 결과 예측이 어렵지 않다. 그러나 복합음(complex tone)으로 범위를 확장해 본다면 결과 예측이 결코 쉽지 않다는 것을 알 수 있다. 먼저, "복합음의 각 주파수 성분들을 파형절취한 후 선형결합하면, 원래의 복합음 자체를 파형절취한 결과와 같은지"의 여부부터 알아보자.

부분음(partial)이 세 개인 복합음을 대상으로 실험을 진행해 보자. 100, 450, 1200Hz의 세 가지 정현파를 가산합성한 신호를 파형절취한 실험결과가 one이라는 배열(array)에 나타나 있고, 각각의 성분에 해당하는 신호를 동일 조건 하에 파형절취한 후 선형결합한 결과가 two라는 배열에 나타나 있다(위상까지 동일하게 맞춰주는 과정을 거쳤다).

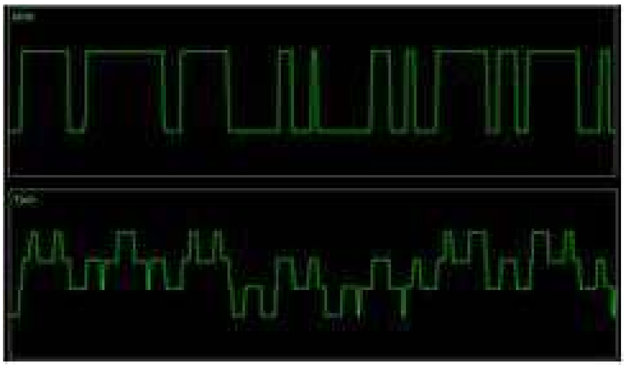


그림 4. 부분음이 3개인 신호를 파형절취한 파형과 세 개의 정현파를 파형절취한 후 선형결합한 파형.

두 실험이 명백히 다른 결과가 나온다는 것을 알 수 있으며, 복합음을 대상으로 하는 파형절취에서는, 각 주파수 성분들을 선형적으로 분리하거나 결합하여 결과를 예측할 수는 없다는 사실을 알 수 있다.

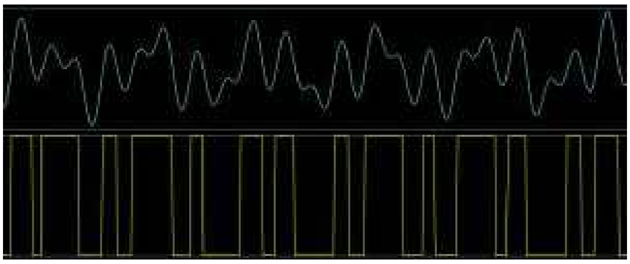


그림 5. 시간축 상에서 관찰한 파형절취 전과 후의 파형.

그림 5의 윗부분에 위치한 신호는 부분음이 세 개인 임의의 신호이고, 아랫부분에는 이를 –0.5~0.5 범위 밖을 파형절취한 후, 관찰의 편의를 위해 두 배로 증폭한 결과를 나타내었다. 그림 5를 자세히 들여다보면, 입력 신호에서의 이웃한 정점(극대, 극소 지점)들이 너무 가까이

붙어 있으면서 단독으로 봉우리를 형성하지 못하는 경우, 파형절취 초기에 신호를 증폭하는 과정에서 이 부분이 함께 증폭된 후 잘려나가 결과적으로는 몇 개의 정점들이 하나로 뭉쳐져 버리는 경우가 자주 생긴다. 이 때문에 복합음의 경우, 아까의 실험에서도 알 수 있었듯 파형 절취 후의 결과 예측이 어렵다.

그렇다면 복합음을 대상으로 한 파형절취 결과는 체계화할 수 없는 것일까? 그림 5에서 파형절취 후의 파형을 관찰하면 몇 개의 듀티 사이클(duty cycle)을 가진 펄스파가 혼재된 형태를 띤다(물론 그 외에도 절취 범위에 못 미칠 법한 매우 작은 크기의 신호가 절취되지 못한 채로 관찰될 수도 있다). 여기서, 몇 가지의 듀티 사이클을 가진 펄스파가 함께 존재하고 있는지의 여부는 당연하게도 입력 신호의 정점(극대, 극소지점)의 "순간 진폭값(표본값)"의 개수와 파형 상의 인접 정도에 의해 결정된다. 지금까지의 논의를 한 문장으로 압축하면 아래와 같다.

> 파형절취법으로 얻은 디스토션 사운드는 주로 몇 가지의 듀티 사이클을 가진 펄스파가 공존하는 양상으로 구성되는데, 이 때의 듀티 사이클의 가지수는 "입력 신호의 정점들에서의 표본값의 가지수" 와 같거나 적다.

전달함수법

두 번째로 소개할 방법은 전달함수(transfer function)법이다. 현재 가장 많이 쓰이는 방법이기도 하고, 체계화가 이미 잘 되어 있는 방법이라 본 연구에서는 다양한 전달함수를 소개하고 그들을 이용한 실험을 해 보는 데에 초점을 맞추었다.

먼저, 이 방법의 장점을 언급하면 다음과 같다. 파형절취법에서는 표본값이 작은 경우, 디스토션에서 누락되는 표본들이 있을 수 있는 반면, 전달함수법에서는 입력신호의 모든 표본들을 전달함수를 이용해 변환하기 때문에 표본값에 따른 디스토션 누락이 발생하지는 않는다는 것이다(여기서 말하는 전달함수는 "항등함수를 포함하는 구간이 아예 없는 경우"를 상정한다. 참고로, 앞서 소개한 파형절취 시스템의 경우 역시 항등함수 구간을 포함하는 전달함수를 갖는 시스템으로 설명될 수 있다). 단, 전달함수법에서는 전달함수의 형태에 따라 입력신호의 표본값에 따라 왜곡률의 차이가 발생하기도 한다.

쌍곡탄젠트 함수(hyperbolic tangent function) "y=tanh x"라는 수식으로 나타낼 수 있는 이 함수는 아래와 같이 생겼다.

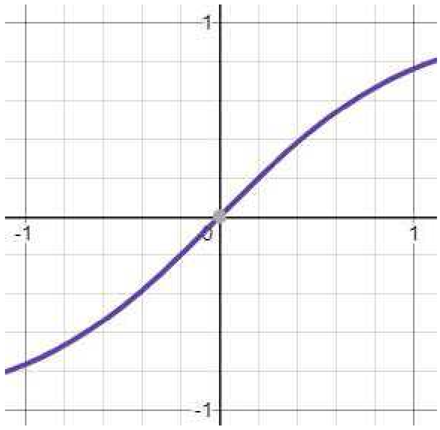


그림 6. y=tanh x 의 그래프 .

그리고 x의 계수가 커지면 기울기는 더 급한 경사를 이루게 된다.

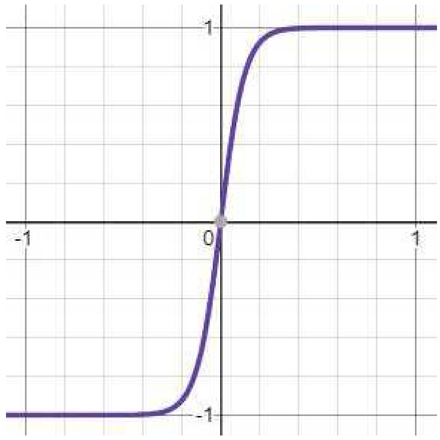


그림 7. y=tanh 20x 의 그래프 .

그림 8. purr-data로 설계한 쌍곡탄젠트 전달함수 시스템.

이 함수를 전달함수로 이용하여 시스템을 만든 후 실험을 하면 아래와 같은 결과가 나온다. 이 방법에서는 조작할 수 있는 변수가 x의 계수인데, x의 계수가 클수록 더 많은 고주파 성분이 포함된 결과가 도출된다. x의 계수를 달리하여 진행한 두 가지의 실험결과를 아래에 보인다.

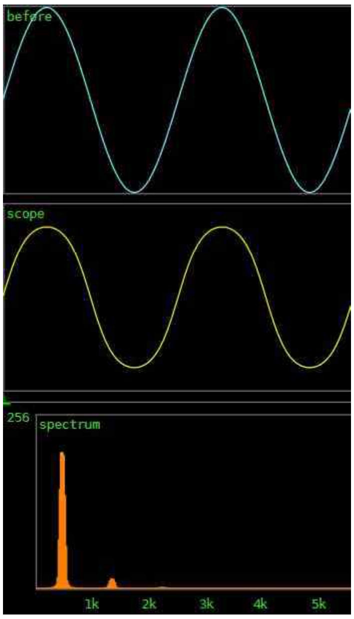


그림 9. 정현파 입력 후, y=tanh x를 전달함수로 설정한 실험결과.
(스펙트로그램 상의 생략된 부분에서는 아무 성분도 관찰되지 않는다)

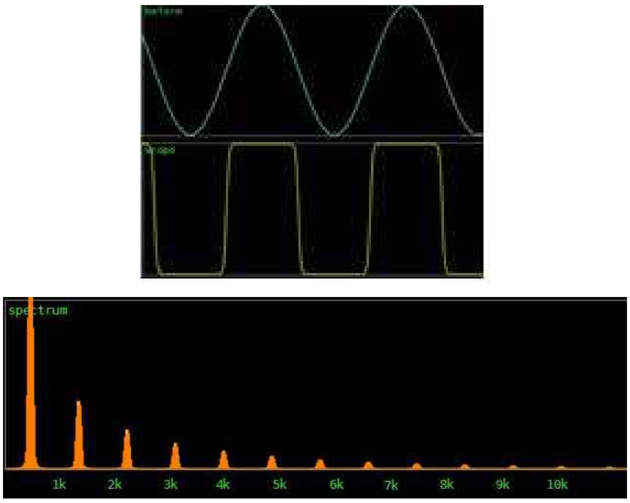


그림 10. 정현파 입력 후, y=tanh 10x를 전달함수로 설정한 실험결과
(스펙트로그램 상의 생략된 부분에서는 아무 성분도 관찰되지 않는다)

이 때, 쌍곡탄젠트 함수의 형태 때문에 x의 계수가 작을수록 출력신호의 진폭도 작다는 것을 기억해야 한다. 쌍곡탄젠트 전달함수 시스템에서는 출력신호의 파형에서 완전히 직각 형태의 클릭이 발생하지 않는다는 사실도 알 수 있다.

그림 10의 아래에 나타난 스펙트럼을 자세히 보면, 홀수번째 배음들만이 나와있는 것을 관찰할 수 있는데 이 이유는 다음과 같이 수학적으로 증명될 수 있다. 여기서 B는 베르누이 수열(Bernoulli Numbers)을 의미한다.

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

이렇게 쌍곡탄젠트 함수는 급수의 형태로 전개될 수 있는데, 위의 식처럼 디스토션을 위해 사인파를 인자로 넣은 경우, 급수를 구성하는 각 항들은 아래와 같이 코사인함수의 거듭제곱꼴로 표현될 수 있다.

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

각 항을 구성하는 코사인함수의 거듭제곱꼴은 삼각함수의 반각 공식(power reducing formula)을 이용하여 아래와 같이 코사인함수의 선형결합으로 분해될 수 있다.

$$\cos^3 x = \frac{3\cos x + \cos 3x}{4}$$

$$\cos^5 x = \frac{10\cos x + 5\cos 3x + \cos 5x}{4}$$

. . .

이 때, cos 2x나 cos 4x 등의 항은 절대 나타나지 않는다. 그래서 결과적으로는 쌍곡탄젠트 함수로 만든 디스토션의 결과에서는 홀수번째 배음들만 존재한다.

유리함수(rational function) 다음으로, 분수함수 형태를 띠는 유리함수를 절댓값 기호를 이용하여 변형하면 이 역시 디스토션을 만드는 좋은 방법이 된다. y=x/(1+|x|)라는 함수를 좌표평면에 나타내면 아래와 같은 형태가 된다.

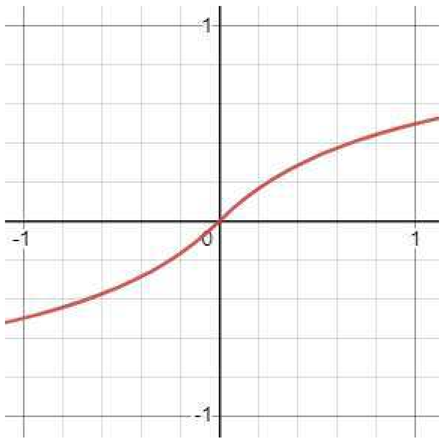


그림 11. y=x/(1+|x|)의 그래프

이를 조금 더 일반화해 본다면, 이 전달함수의 꼴을 "y=x/(a+b|x|)"로 나타낼 수 있을 것이다. a가 작아지면 그래프 상의 경사가 급해지며, b가 커지면 전체 함숫값이 동일한 비율로 줄어든다.

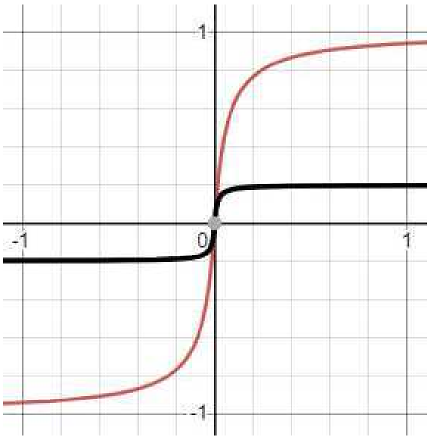


그림 12. 빨간색: y=x/(0.06+|x|) 검정색: y=x/(0.06+5|x|)

이 전달함수를 이용한 디스토션 시스템을 구현한다면 아래와 같다.

그림 13. purr-data로 설계한 유리전달함수 시스템

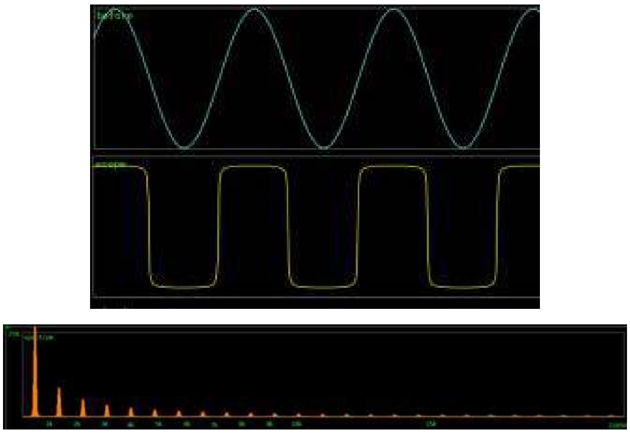


그림 14. y=x/0.06+1.16|x|을 전달함수로 설정한 시스템의 입출력 결과 파형과 스펙트럼

a의 값이 작을수록 출력신호에서 고주파 성분이 더 발생하며, 출력신호의 진폭은 b의 값으로 조절할 수 있다.

시그모이드 함수(sigmoid function)

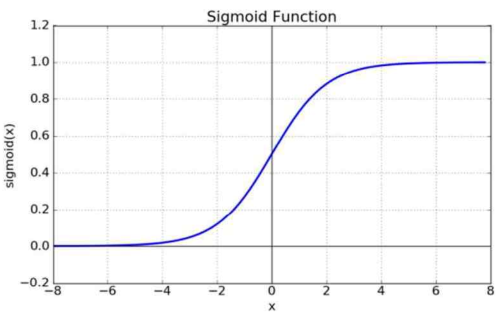


그림 15. 시그모이드 함수의 그래프

위의 그래프는 아래의 식을 도시한 것이다.

$$y = \frac{e^x}{e^x + 1}$$

이 함수를 시그모이드(sigmoid) 함수라고 하는데, 이를 전달함수로 갖는 디스토션 시스템을 구현하고, 결과를 관찰하면 아래와 같다.

그림 16. purr-data로 설계한 sigmoid 전달함수 시스템

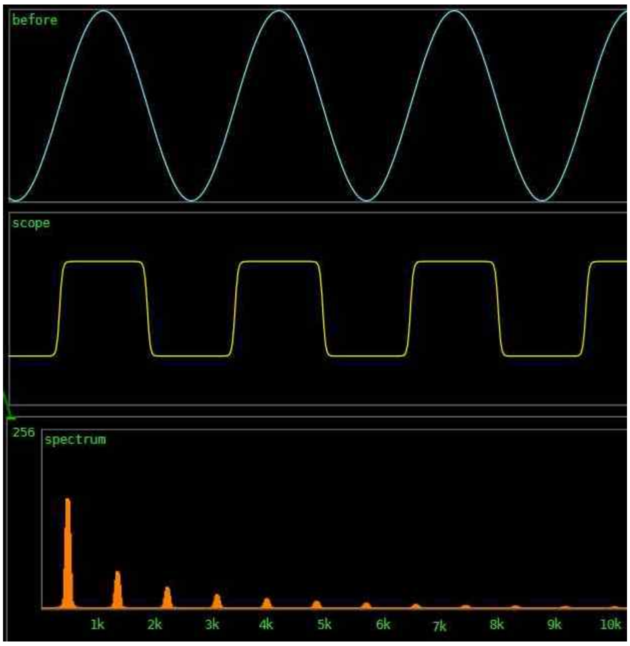


그림 17. sigmoid 함수를 전달함수로 이용한 디스토션의 결과 파형과 스펙트럼 (스펙트로그램 상의 생략된 부분에서는 아무 성분도 관찰되지 않는다)

그림 16을 잘 보면 전달함수의 효과적인 이용을 위해 입력신호를 8배 증폭하여 쓰고 있는데, 이 숫자가 커질수록 더 가파른 경사가 출력 신호에서 관찰되며 숫자가 작아지면 그 반대가 된다. 이 실험에서는 8배 증폭하여 이용했지만, 그 외의 수치를 이용하여도 무방하다.

단절점을 포함하는 전달함수 마지막으로 소개할 전달함수는 "단절점을 포함한 전달함수"이다. 기성 기타 이펙터에서도 자주 쓰이는 방법이기도 한 이 방법은 표본값의 급격한 변화를 유도하여 클릭(click)을 입력 신호에 삽입하는 결과를 얻게 된다.

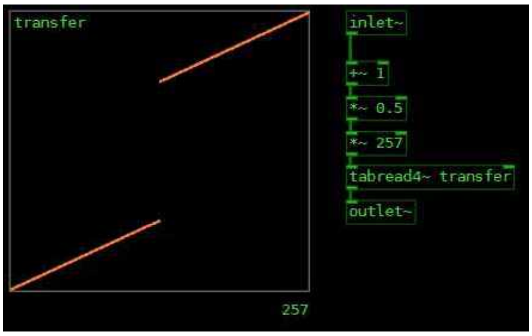


그림 18. purr-data로 설계한 단절점을 포함하는 함수를 전달함수로 갖는 시스템

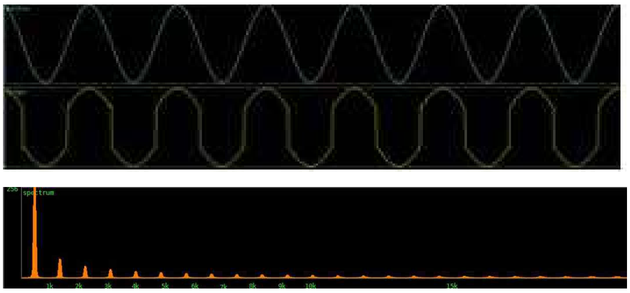


그림 19. 그림 18의 함수를 전달함수로 갖는 시스템을 통한 디스토션의 결과 파형과 스펙트럼

때에 따라서는 아래처럼 표본값 자체의 변화 정도는 비교적 덜하지만, 클릭을 단위시간 내의 여러 지점에 삽입하도록 만드는 전달함수를 디자인할 수도 있다.

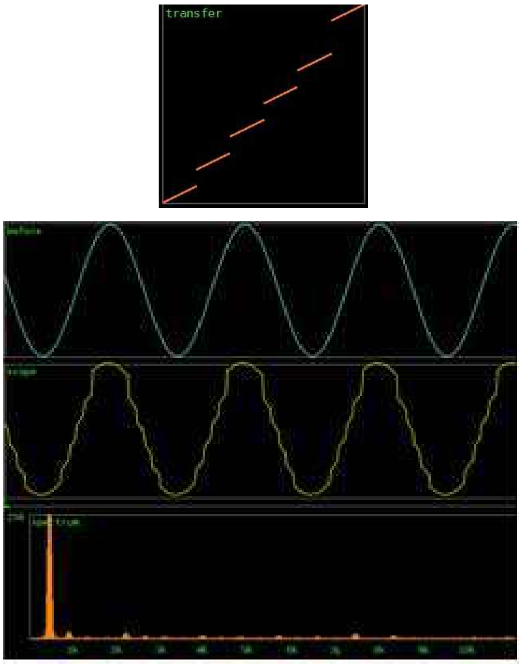


그림 20. 또 다른 형태의 단절점을 포함하는 전달함수를 이용한 디스토션의 예시 (스펙트로그램 상의 생략된 부분에서는 미소값들만이 관찰된다)

표본지속법

이 방법은 종래에는 주로 bit-crushing이라는 이름으로 불려왔으나 본 방법의 메커니즘에 의거, 본 연구에서는 이를 표본지속법으로 명명하기로 한다. 표본지속법은 [samphold~] 오브젝트를 이용하여, 트리거 신호로 이용되는 톱니파가 새 주기를 시작할 때마다 이전에 지속시키고 있던 입력신호의 표본값을 새로운 값으로 대체하여 지속시키는 방법을 통해 사각형 모양의 파형을 아래와 같이 만들어낸다.

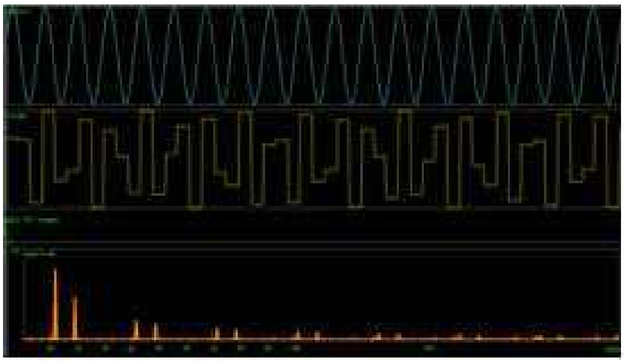


그림 21-1. 표본지속법으로 왜곡한 신호의 예시 1-1

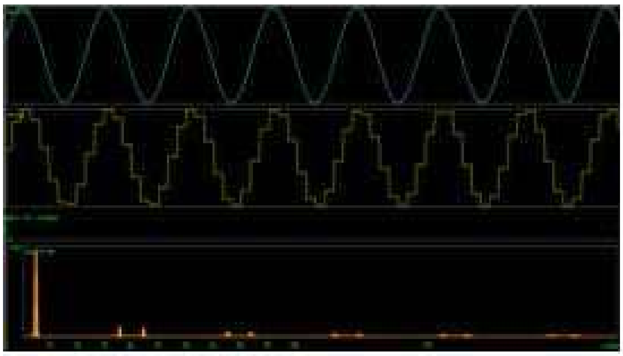


그림 21-2. 표본지속법으로 왜곡한 신호의 예시 1-2

파형에서는 네모난 파형들이 같은 주기로 나타난다 (표본을 지속하기 위해 쓰인 트리거 신호의 주파수는 일정하므로). 노란색 파형을 관찰해 보면, 진폭이 다른 사각파가 규칙적이고 매우 빠르게, 교대로 나타나는 것과 같은 양상을 보인다.

스펙트로그램 상에서는 매우 재밌는 결과가 관찰된다. 우선 입력신호를 정현파 하나로 설정한 경우를 생각해보자. 정현파의 주파수를 0부터 시작하여 위로 올려주게 되면, 이 상승하는 주파수를 기음으로 삼는 스펙트럼의 움직임이 관찰되는데, 눈에 띄는 점은 측파대가 **"두 개씩 짝지어 등장"**한다는 사실이다. 아래의 예시를 보자.

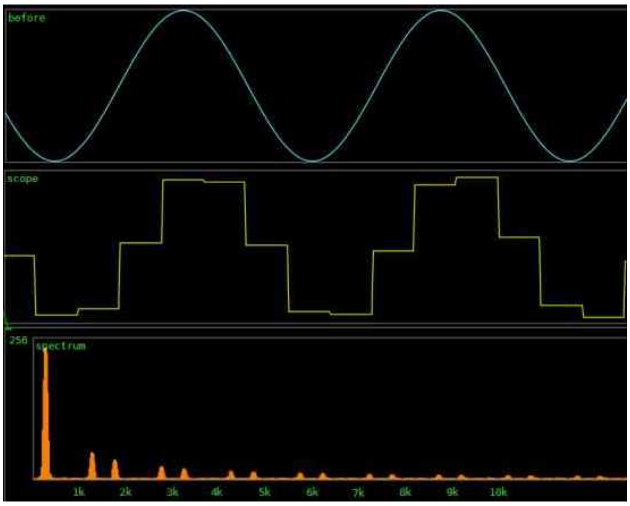


그림 22. 표본지속법의 예시 2-1

그림 22에서, 표본지속을 위해 쓰인 트리거 신호인 톱니파의 주파수는 1500Hz이고 입력신호인 정현파의 주파수는 245Hz이다. 입력신호의 주파수 성분은 왜곡 이후에도 사라지지 않고 남아 있다. 앞서 말한 것처럼 기음 위로 측파대들이 두 개씩 짝지어 나타나는데, **이 두 개씩 짝지어진 측파대들의 주파수 상의 중점은 트리거 신호를 위해 쓰인 톱니파의 주파수의 n배와 같다. 그리고 이 짝지어진 측파대들의 간격은 기음 성분의 주파수의 2배와 같다.**

이 상황에서 정현파 입력신호의 주파수를 500Hz까지 상승시키면, 아래와 같은 결과를 얻는다(트리거 신호의 주파수는 여전히 1500Hz다).

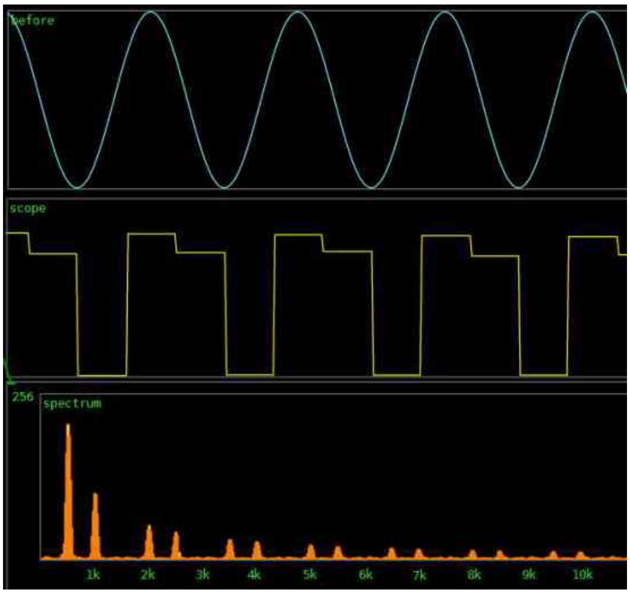


그림 23. 표본지속법의 예시 2-2

그림 22에서 입력신호의 주파수가 245Hz였을 때에 두 번째 측파대였던 성분이 강도가 점차 커짐과 동시에 아래로 내려오면서 기음 성분과 서서히 가까워진다. 이 때, 앞서 말한 성질대로 기음 위로 짝지어 나타난 측파대의 중간지점들은 톱니파 주파수의 정수배와 같다.

정현파 입력신호의 주파수를 더 상승시켜 보자. 트리거 신호인 톱니파 주파수의 절반과 같은 주파수인 750Hz까지 입력신호의 주파수가 올라간다면, 측파대끼리 만나는 지점이 되어 출력신호는 사각파와 같은 형태가 된다. 아래 실험결과를 보자(톱니파: 1500Hz, 입력 신호: 750Hz의 정현파).

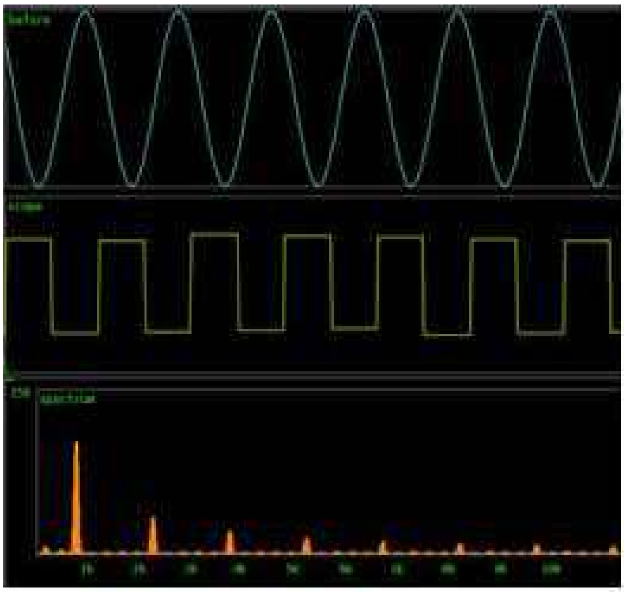


그림 24. 표본지속법의 예시 2-3

이 상태에서 다시 정현파 입력신호의 주파수를 올리면 1500Hz에 도달할 때까지는 지금까지 일어났던 변화가 역방향으로 일어난다. 즉, 입력신호의 주파수가 0Hz에서 750Hz로 이동할 때의 역방향인 750Hz에서 0Hz로 이동할 때와 똑같은 변화가 750Hz에서 1500Hz로 이동할 때에 일어난다. 그러므로 입력신호의 주파수보다 낮은 주파수 성분이 출력신호의 스펙트럼에서 관찰되기 시작한다. 이 상태에서 입력신호 정현파의 주파수를 계속하여 1500Hz 이상으로 상승시킨다면, 상기한 변화가 매 1500Hz마다 주기적으로 발생한다.

이제 이러한 현상이 일어나는 이유를 알아보자. 위의 실험들에서 보이는 출력신호 파형을 시간축 상에서 재구성하면 아래와 같다.

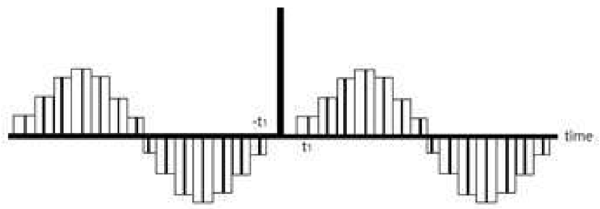


그림 25. 표본지속법의 출력신호 파형의 한 예시

이와 같은 파형을 유도해 내는 과정을 통해 표본지속법의 결과의 이유를 증명해 볼 것이다.

주파수가 f_0Hz인 정현파를 주파수 축 상으로 푸리에 변환하면 아래와 같다.

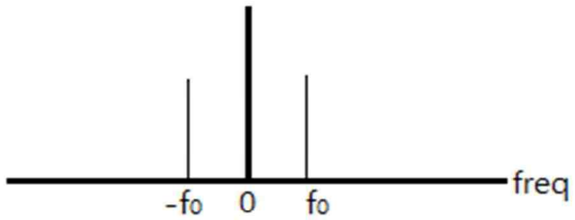


그림 26. f0Hz인 정현파의 푸리에 변환

그리고, 주기가 $1/f_1(=t_1)$인 임펄스열(impulse train)을 주파수 영역으로 푸리에 변환하면 아래와 같다.

그림 27. 주기가 1/f1인 임펄스열의 푸리에 변환

다음으로, 주파수가 f_0Hz인 정현파와 주기가 $1/f_1(=t_1)$인 임펄스열을 시간 영역 상에서 곱하면 그림 28과 같다. 이 과정에서 일종의 표본화(sampling)가 발생하는 것과 같은 결과를 얻을 수 있다.

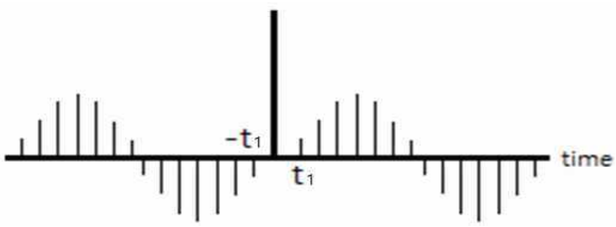


그림 28. 1/f1이 주기인 임펄스열과 f0Hz 정현파의 시간 영역 상의 곱

그림 28을 주파수 영역으로 푸리에 변환한 것은 주파수 영역 상의 그림 26과 그림 27 간의 합성곱(convolution) 연산과도 같다. 아래를 보자.

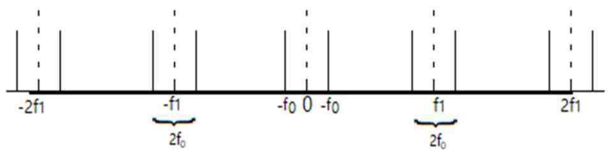


그림 29. 그림 28의 푸리에 변환

우리의 목적은 그림 25와 같은 형태의 파형을 유도하는 것이다. 그렇게 하기 위해서는 그림 30에 나타낸 직사각 함수(rectangular function)와 그림 28 간의 합성곱 연산이 이루어져야 한다.

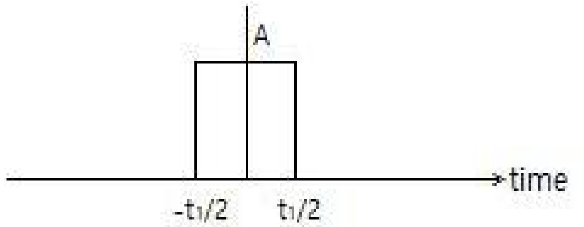


그림 30. 직사각 함수 (정의역의 크기: M)

그림 25에서의 파형의 주파수축 상의 스펙트럼을 얻기 위해서는 그림 29와 직사각 함수의 푸리에 변환 결과를 주파수 도메인 상에서 곱해야 한다(직사각 함수의 푸리에 변환 결과는 sinc함수임).

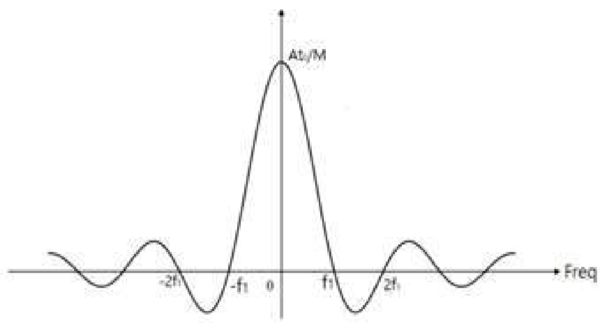
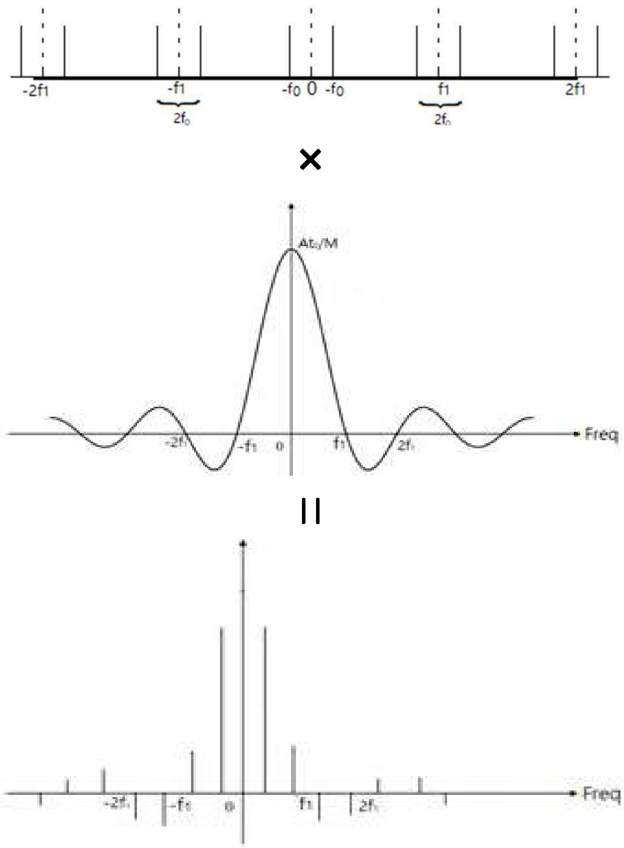


그림 31. 그림 30의 푸리에 변환이자 sinc 함수 (정의역의 크기: M)

곱하는 과정을 그래프로 나타내면 아래와 같다.



이 유도과정을 통해 표본지속법의 스펙트럼 상의 결과에 대한 원인을 알 수 있다.

반올림법

마지막 방법은 신호를 반올림(rounding)하여 신호 자체에 계단 형태의 모양을 내어 주는 방법이다. 신호 자체를 그대로 반올림하면 값이 다양하지 못하게 나올 우려가 크므로 적당히 다양한 종류의 표본값을 유도하기 위해 신호를 처음에 증폭하고 출력 직전에 줄여주는 작업을 거치기로 한다. 여기서는 증폭도를 실험 내내 5라는 임의의 값으로 고정해 두었다.

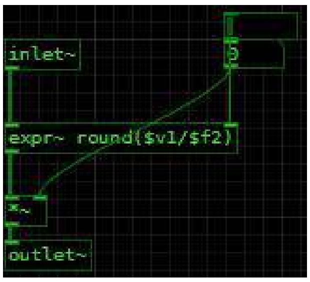


그림 32. purr-data로 설계한 반올림법 시스템 (증폭도는 나타나 있지 않다)

$f2의 자리로 들어가는 변수는 0에서 1 사이의 값이며 작은 값일수록 다양한 표본값을 만들어낼 수 있다. 이외에도 반올림법은 다양한 방법을 통해 구현될 수 있음을 밝힌다.

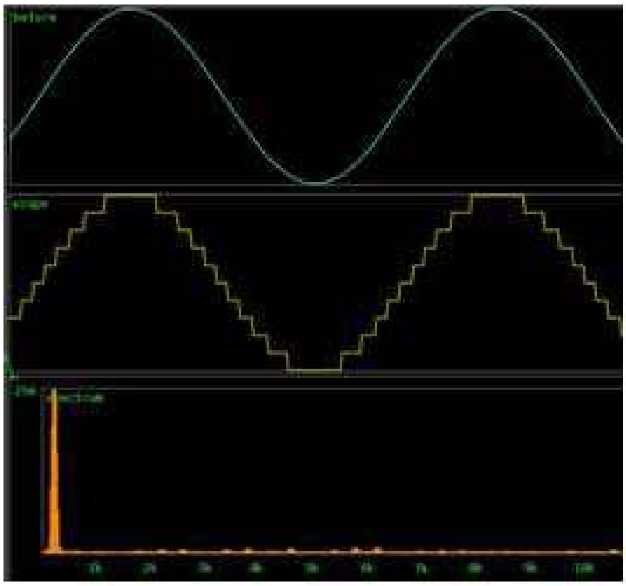


그림 33. 반올림법 디스토션의 예시

반올림법의 결과의 배음 구조를 체계화하기는 힘들어 보인다. 입력신호로 정현파를 넣는 경우조차 계단의 간격이 제각각인 데다가, 복합음의 경우는 아예 출력신호의 배음 구조를 거의 예측 하기 어려울 것이다. 그림 33 같은 경우, 입력신호에 디지털 노이즈가 광범위하게 낀 듯한 효과가 발생한다. 참고로, 정현파를 입력한 반올림법 시스템 출력신호와 입력신호의 차이를 구하면 아래와 같이 주기성을 띤 고주파 신호가 나온다.

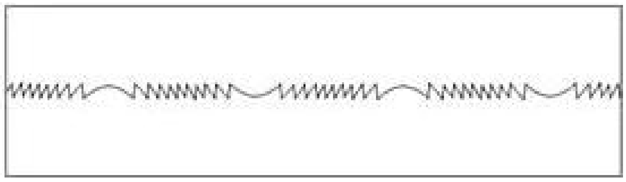


그림 34. 반올림법에서의 입출력 신호의 차

확장된 디스토션의 방법들

급격하면서 주기적인 음고 변화 유도하기 (복합음을 대상으로 FM 적용)

복합음을 대상으로 급격하고 주기적인 음고변화(이하 복합음 FM으로 칭함)를 유도하면 꽤 복잡하고 지저분한 배음구조를 얻어낼 수 있고, 자연히 입력신호에 비해 급격한 표본값의 변화를 유도해 내어 디스토션의 효과를 얻을 수

있다. 이 방법은 지연회로에서의 지연시간을 정현파 신호로 부여하는 방법으로 구현되었다. 그림 35를 보자.

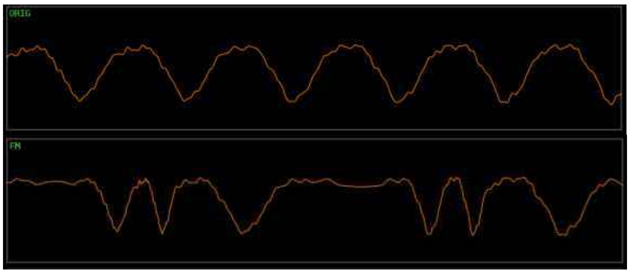


그림 35. 복합음 신호를 대상으로 급격하고 주기적인 음고 변화(FM)를 유도한 파형

위가 입력신호이고, 아래가 왜곡된 신호다. 그림 35에서의 입력신호 주파수는 거의 일정한데, 위의 왜곡된 신호는 같은 시간 내에서도 입력 신호에 비해 표본값의 변화 정도가 비교적 큰 부분들이 존재하고 있음을 알 수 있다. 복합음 FM을 위한 패치는 아래와 같다.

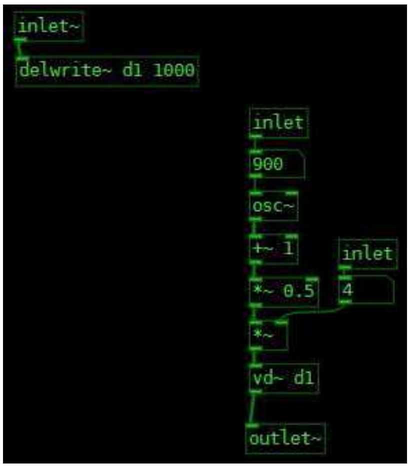


그림 36. purr-data로 설계한 복합음 FM 시스템

임계대역 안의 비교적 낮은 숫자를 [osc~]의 주파수로 넣으면 펄스가 느껴지는 신호가 출력되어 나오지만, 적당히 높은 숫자(위처럼 900 정도)를 넣게 되면 출력신호는 고배음이 많이 첨가된 신호의 형태가 된다. 이 주파수는 결국 단순 FM합성법(정현파끼리의 FM)처럼, 형성되는 부분음들의 간격이 된다. 그 옆 인렛으로 들어가는 수치는 변조 지수(modulation index)와도 같은 역할을 하는데, 이것이 너무 높으면 입력신호의 기음 성분이 다른 주파수 성분들에게 묻혀서 잘 들리지 않게 되고 너무 낮으면 고주파 성분이 잘 들리지 않게 된다. 본 연구에서는 변조 지수를 4로 설정했다. 참고로, 이 값은 배음 성분이 위치하는 주파수 축 상의 범위와 비례한다. 이 값이 2배가 되면 출력신호가 분포되어 있는 주파수의 범위가 2배 가량이 넓어지며, 3배가 되면 역시 주파수의 범위도 3배 가량 넓어진다.

아래에는 이 방법으로 구한 신호의 스펙트럼 상의 모습과 파형 상의 결과가 있다. 스펙트럼 상에서도 기타 사운드의 부분음들이 각각 FM 합성된 것처럼 여러 봉우리들이 기음을 기준으로 정수배의 지점에서 동시다발적으로 생기고 있음을 관찰할 수 있다.

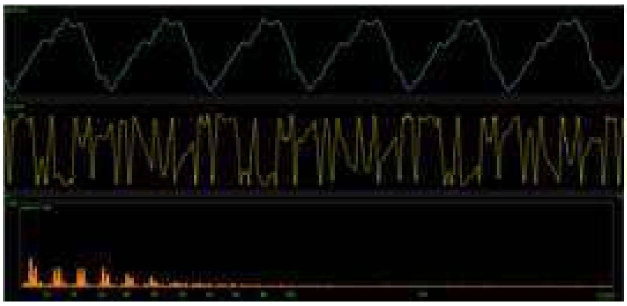


그림 37. 복합음을 대상으로 급격하고 주기적인 음고변화를 적용한 예시

노이즈가 포함된 항등함수를 전달함수로 사용하기

앞서 소개했던 전달함수법을 응용한 것으로, 아래와 같이 항등함수의 주변으로 무작위적인 노이즈가 낀 함수를 전달함수로 이용하는 시스템을 설계해 보았다.

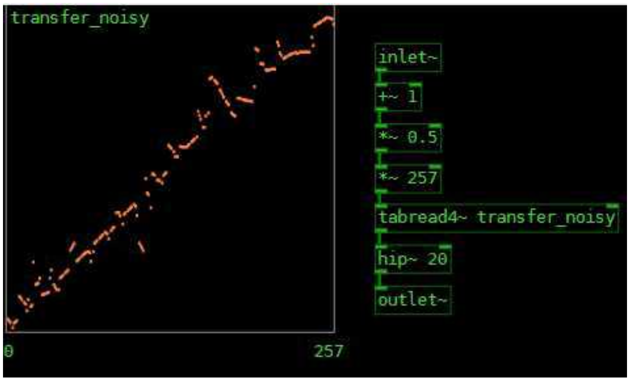


그림 38. purr-data로 설계한 노이즈가 낀 항등함수를 전달함수로 갖는 시스템

아래의 파형과 스펙트럼을 보자. 바로 위에 명시된 전달함수를 이용한 결과이며 입력 신호는 440Hz의 정현파다.

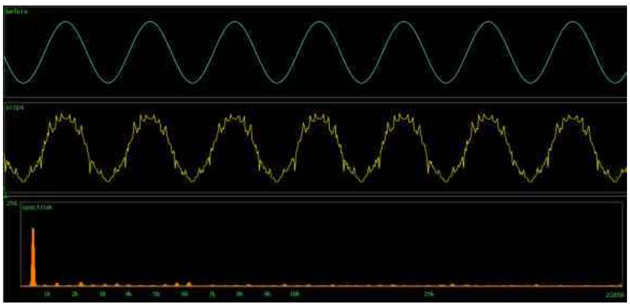


그림 39. 그림 38의 시스템을 이용한 정현파 왜곡의 결과

이 실험에서 생긴 노이즈 성분은 주기 신호이다. 아래는 정현파 왜곡 과정에서 생긴 노이즈 성분만을 나타낸 파형이다. 전달함수가 무작위값을 포함하고 있다고 하더라도 이 함숫값들은 고정값이므로 입력신호가 완벽한 비주기성 신호가 아닌 이상은 출력신호에서 발생하는 노이즈 성분은 주기신호의 형태가 될 가능성이 높다.

그림 40. 노이즈를 포함한 항등전달함수 시스템의 정현파 왜곡 결과에서 노이즈 성분만 추출한 파형

전달함숫값이 무작위값인 시스템

전달함수 자체를 완전히 무작위적인 값들로 구성하면 어떻게 될까? 아래와 같은 방법으로 구현해 보았다.

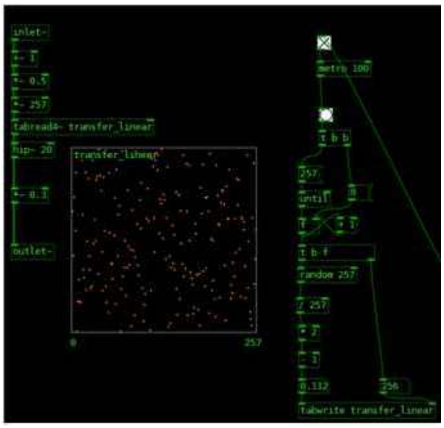


그림 41. 전달함수 자체가 무작위값들로 구성된 시스템

그림 41의 실험결과는 아래와 같다.

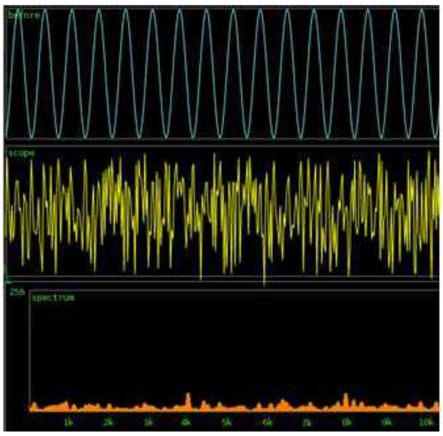


그림 42-1. 전달함수 자체가 무작위값인 시스템의 변환 결과_1 (입력신호: 2000Hz의 정현파)

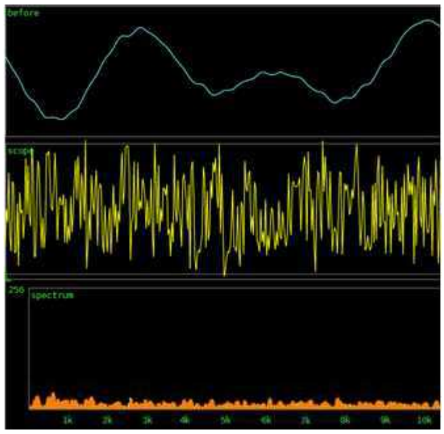


그림 42-2. 전달함수 자체가 무작위값인 시스템의 변환 결과_2 (입력신호: 전기기타 신호)

결과를 관찰하면 입력신호와는 완전히 상관없어 보이는 출력신호의 파형이 보인다. 그리고 스펙트럼은 완전한 화이트 노이즈의 스펙트럼과 다를 것이 없어 보인다.

그러나 이 시스템을 통과하여 왜곡 변환된 후에도 출력신호에서는 음고가 꽤 명확하게 인지되는 편인데, 이런 현상이 발생하는 이유는 다음과 같이 설명할 수 있다. 먼저, 전달함수로 쓰이는 테이블 상의 함숫값들이 충분히 빠른 주기로 교체되지 못했기 때문이다. 이를 다른 말로 바꾸면, 입력신호의 주기와 동일한 시간 혹은 더 짧은 시간 간격으로 전달함숫값들을 교체하게 되면 입력신호의 피치는 완전히 없어지게 된다.

본 연구에서는 입력신호의 기음에 해당하는 주파수 성분을 출력신호에서 관찰할 수 있어야 하므로, 입력신호의 주기보다 충분히 긴 시간 간격으로 전달함숫값을 교체해 주어야 할 것이다(적어도 전달함수 테이블을 여러 번 반복적으로 읽어야 음고를 느낄 수 있는 결과를 얻게 되기 때문이다). 예를 들어 전기 기타의 가장 낮은 음은 164Hz 정도인데, 이 신호의 한 주기는 0.006초 정도 된다. 만약, 이 입력신호의 음고를 완전히 없애고 싶다면 그림 41에서의 [metro] 오브젝트의 인자를 6 이하의 값으로 설정하면 된다. 반대로 디스토션으로의 기능을 하게 하려면 [metro]의 인자를 6의 수 배 이상으로 설정을 해 주어야 할 것이다.

신호천공법

무작위적인 길이로(본 연구에서는 대략 수 ms 정도로 제한하였다), 그리고 무작위적인 타이밍마다 신호의 표본값을 0으로 만들어버리는 시스템을 구성했고, 신호에 구멍을 내는 것과 같은 메커니즘을 본따서 이 방법을

"신호천공법"으로 명명했다. 여기서 신호의 표본값을 스위치처럼 켜고 끄는 듯한 역할을 해 주는 것은 별도로 만든 펄스 신호다. 이 펄스 신호를 만드는 패치는 그림 43에 나타나 있다. 그리고 이 펄스 신호를 이어받아서 그림 44에서처럼 신호의 표본값들을 스위치를 켜고 끄듯 조작한다.

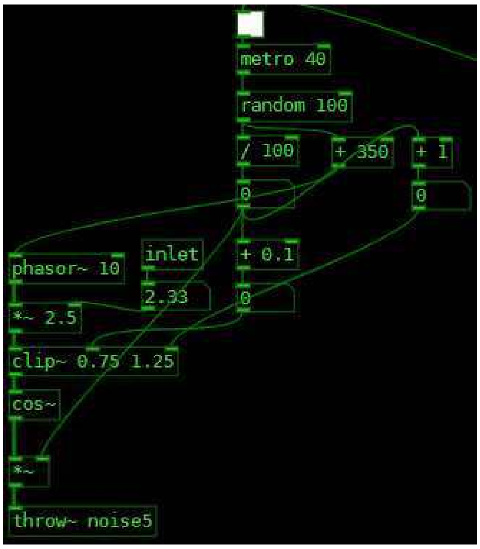


그림 43. 무작위적인 (수 ms범위)길이의 펄스를 랜덤한 시간마다 만들어내는 패치

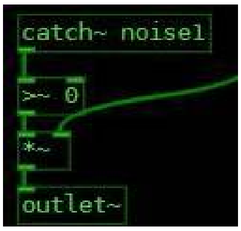


그림 44. 그림 43를 받아서 입력신호를 왜곡하는 시스템

신호를 조작하는 데에 이용되는 무작위적인 형태의 펄스들은 패치에서 보이듯이, 일부가 절취된 톱니파의 표본값들을 [cos~]의 입력값으로 이용하여 만들어지며, 아래와 같은 형태를 띠는데 펄스의 높이와 길이, 발생 시점은 무작위적이다. 이때, 어느 정도 보간(interpolation)된 펄스들이 스위치와도 같은 기능을 하기 때문에 입력신호에 클릭을 삽입하는 것과는 다른 맥락의 방법이다.

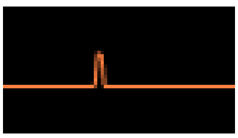


그림 45. 신호천공법에 쓰이는 무작위적 펄스의 한 예시

그리고 신호천공법을 통해 변환된 신호를 최종적으로 6겹으로 겹쳐서 무작위성을 더 심하게 만들어 노이즈를 더 고르고 풍성하게 들리도록 하였다. 이를 통해 미루어 보면, 신호천공법은 일종의 입상합성법(granular synthesis)과 비슷한 원리로 이해하는 것도 가능하다(단, 창함수를 곱하는 과정-windowing-이 제외된 형태이다). 신호천공법에서는 앞서 언급한 모든 방법들과 비교해 봤을 때, 부가적으로 생기는 노이즈 성분이 무작위적 가산 노이즈(random additive noise)와 가장 흡사하다.

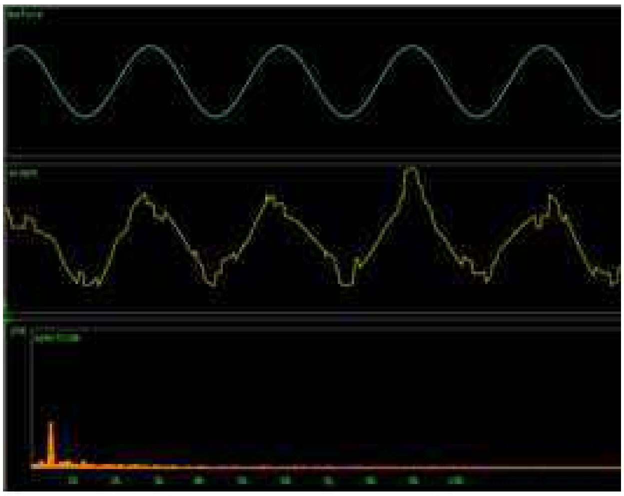


그림 46. 6겹 신호천공법 결과의 예시

디스토션 방법의 카테고리화

앞선 단락들에서 논의한 디스토션의 방법은 크게는 총 8가지이다. 이들을 특징에 따라 분류하여 각 방법들의 특성을 더 명확하게 파악해 보고자 한다. 먼저 파형 상의 특징을 근거로 그에 해당하는 방법들에는 무엇이 있는지 알아보자.

앞서 논의한 방법들 중에서 첫 번째로는 "시간축(가로축)상에서의 표본값 지속"을 통해 고주파수의 성분들을 만드는 방법들이 있다. 두 번째로는 "순간 진폭(세로축)의 급격한 변화, 표본값의 단절, 혹은 첨점을 유도"하여(즉, 클릭을 신호에 삽입하는 방법으로) 고주파 성분을 만드는 방법도 있다. 이 방법 둘 다에 해당하는 경우도 있으며, 완전히 이 둘의 카테고리에 포섭되지는 않으나 어느 한 쪽에 조금 더 가까운 형태의 중간태로 분류될 수 있는 경우도 있다. 아래의 표를 보자.

시간축에서의 표본값 지속	*파형절취법 *표본지속법 *반올림법 *신호천공법
세로축에서의 급격한 변화 혹은 단절	*노이즈 포함 항등전달함수 *무작위값 전달함수 *신호천공법 *첨점을 포함하는 전달함수
시간축에서의 표본값 지속에 가까운 중간태	*쌍곡탄젠트 전달함수법 *시그모이드 전달함수법 *분수함수 전달함수법
세로축에서의 급격한 변화나 단절점 유도에 가까운 중간태	*주기적이고 급격한 음고 변화 유도(FM)

그림 47. 디스토션 출력파형의 특성에 따른 분류

이렇게 여러 카테고리로 분류가능한 디스토션 방법들은 상당 부분이 파형성형(waveshaping)에 기반을 둔 방법으로 구현되었다는 공통점을 가지고 있기도 하다.

결론

지금까지 여러 방법의 디스토션들을 패치의 형태로 구현하고 각각의 특성들을 살펴본 후, 마지막으로 이들을 분류해 보았다. 본 연구에서 살펴본 디스토션의 방법에는 시간축 상에서의 표본의 지속을 유도하는 방법과, 세로축에서의 표본값의 도약 혹은 단절을 유도하는 방법, 그리고 완벽히 이 두 방법에 속하지는 않지만 근접한 중간태로 분류될 수 있는 방법들이 존재했다. 이 방법들로 구성된 시스템을 통과한 출력신호에서는 입력신호에서는 비중이 적거나 없었던 고주파수 성분들이 다량으로 발생한 것을 관찰할 수 있었다. 전달함수로 설명될 수 있는 방법이 다수였으며, FM의 영역에 포함될 수 있는 방법과 입상합성법, 표본화와 같은 기존에 존재하던 오디오 이론의 변형된 형태로 설명 가능한 방법들도 있었다.

추가 연구의 방향

더 나아가, 시중의 제품화된 기성 디스토션 이펙터들은 단순히 디스토션 과정만을 탑재하고 있는 것은 아니다. 시스템을 구성하는 여러 변수들의 조작을 통해 전처리와 후처리 과정에서 신호에 변화를 줄 수 있으며, 디스토션이 일어나는 과정 중에서도 추가적인 신호 변형이 일어나는 경우도 많다. 예컨대, 가장 대중적으로 이용되고 있으며, 파형절취법("Hard-clipping"으로 설명하고 있다) 기반의 전기 기타용 디스토션 페달인 BOSS DS-1 페달에 100Hz의 정현파를 입력한 후에 level, tone, dist 등 세 가지의 노브를 큰 값으로 치우치게 한 후 출력신호의 파형을 관찰한 결과를 아래에 보인다. 주된 부분 외에도 여러 부수적인 신호처리 회로들이 존재하고 있음을 짐작할 수 있다.

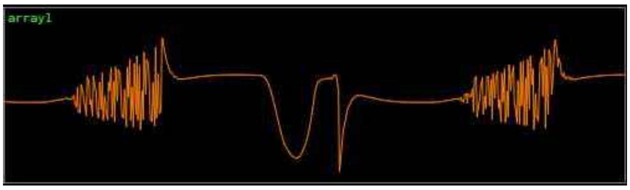


그림 48. BOSS DS-1을 통과한 정현파

본 연구에서 언급한 여러 디스토션의 방법들이 기성 악기를 위한 이펙터로서의 역할을 제대로 하기 위해서는 디스토션 그 자체만이 아닌 변환 과정에서의 부수적인 신호처리를 어떻게 해 줄 것인지, 그리고 시스템에서의 적절한 변수값들을 찾는 등의 추가적인 연구가 필요할 것이다. 그 외에도 본 연구에서는 사각파와 같은 형태의 파형을 만들어내는 전달함수들만을 전달함수법 카테고리에서 설명했는데, 조금 더 다양한 형태로 입력신호를 왜곡할 수 있는 전달함수도 연구할 수 있을 것이다.

참고문헌

한국음향학회. (2003). 음향 용어 사전

BOSS DS-1 Distortion Analysis. Retrieved from https://www.electrosmash.com

Devi, R. Ramya./ Pugazhenthi, D. (2016). *Ideal Sampling Rate to reduce distortion in Audio Steganography*.

Distortion Article(Eng/Kor). Retrieved from https://en.wikipedia.org/wiki/Distortion

Guitarextended. (2011). *Simple Fuzz effect with Pure Data*. Retrieved from https://guitarextended.wordpress.com

Herman, Woody. *DSPFuzz: a guitar distortion pedal using the Stanford DSP sheild*

Kreidler, Johannes. (2009). *Loadbang: Programming Electronic music in Pd*.

Son, Hoseok. (2009). *Digital Effector Implementation Using a DSP Board*.

Timoney, Joseph./ Lazzarini, Victor./ Gibney, Anthony./ Pekonen, Jussi. (2010). *Digital Emulation of Distortion Effects by Wave and Phase Shaping Methods*.

Yeh, David Te-Mao. (2009). *Digital implementation of musical diostortion circuits by analysis and simulation*.

Cinematic Audiovisual Composition

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This paper aims to briefly elaborate practice-led research — an experiment by the authors on utilizing game-engine virtual cameras to present visual elements of an audiovisual composition "Supernova" through the application of cinematographic camera techniques. It also includes a discussion on the Interactive System created to control the virtual camera and audio parameters in real-time during the performance.

Keywords: Audiovisual Composition, Interactive System, Game, Electronic Music, Virtual Production

Background and Related Works

The dynamic movement of camera position and angle appears to be a neglected aspect of audiovisual composition that employs 3D visual materials. This has resulted because most visual presentations utilise audio-reactive methods that commonly only manipulate the object's transform (position, rotation, scale) or specific behavioural parameters. 1 Nevertheless, with the increasing usage of the game-engine as an interactive tool, the visual perspectives of computer games, particularly First-Person and Third-Person shooters, have been adopted as visual presentation methods.

This procedure positions the sight of users from the game avatar perspective, in which the attached camera, and its locomotion are real-time controllable within the three-dimensional space (Wolf et al 2013). Interactive audiovisual work by Ricardo Climent, Putney "K" (2014), and Rob Hamilton "ECHO::Canyon (2013)" exemplifies how the method is implemented (see figure 1 & 2).

Figure 1. ECHO::Canyon (2013)[2].

However, although the visual presentation in the works of Climents and Hamilton has been assigned via real-time camera movements, its functionality does not focus to cinematically displaying the visual elements through the application of specific camera techniques and other related visual aspect such as lighting.

This article discusses the implementation of cinematographic camera techniques on virtual cameras similar to virtual production in three-dimensional space using a game engine. It provides technical details of the interactive system and describes its implementation on an audiovisual composition, "Supernova."

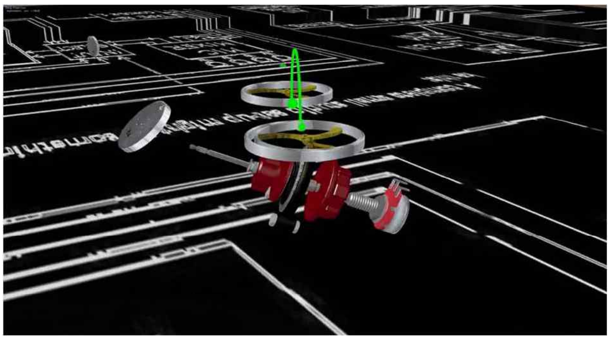


Figure 2. Putney "K."3

Virtual Production

Virtual Production is a new and revolutionary movie-making method that combines real-time 3D computer graphics, virtual camera systems, motion capture technologies to execute the production idea instantaneously in real-time (see figure 3). Unreal Engine is currently a widely used software as it provides practical features and workflows, allowing people without an advanced technical background to able execute the production.

In common practice, motion tracking is attached to a physical camera (see figure 4) that determines virtual camera parameters simultaneously within the 3D environment to conduct specific camera techniques. However, due to performative considerations, the virtual camera for this project is controlled interactively via an Xbox game-pad[4] (see live interactive design).

Figure 3. Virtual Production — The Mandalorian.[5]

Figure 4. Virtual Camera Setup.[6]

Besides only replacing the green screens in conventional film production, virtual production has been adopted for animated movie-making—fully computer graphics: Bennett & Carter, 2014 proposed practical strategies in utilizing virtual production on short, animated films. Within their experiment, besides using motion tracking to configure the virtual camera parameters, they also employed the motion tracking to control the 3D character expressions-movements interactively in real-time.

"Supernova" adopted a similar approach in which all visual elements are computer-generated images presenting in real-time, including the whole virtual environment entities. Nonetheless, the interactive workflow is adapted accordingly based on the performative necessities to provide practical workflows for the performer during the show.

Implementation and System Design

'Supernova' — Cinematic Audiovisual Composition

"Supernova" is an interactive audiovisual composition (see figure 5) inspired by the astronomical phenomenon when a giant stellar runs out of nuclear fuel. In this process the star eventually cannot withstand its gravitational force, collapses, and causes a massive supernova explosion (Dunbar, 2018).

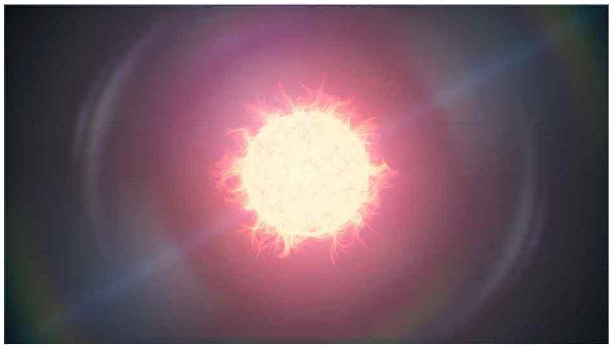


Figure 5. Visualization of Red Giant star using Unreal Engine.

Thus far, scientists have visualized and simulated the supernova process using 3D computer graphic technology. One example has been created by the Princeton University Supernova Theory Group that depicts the early phases of the explosion that prioritizes the visualization-simulation of physics events; angular momentum, shock wave, proton-neutron star shrinkage (see figure 6).

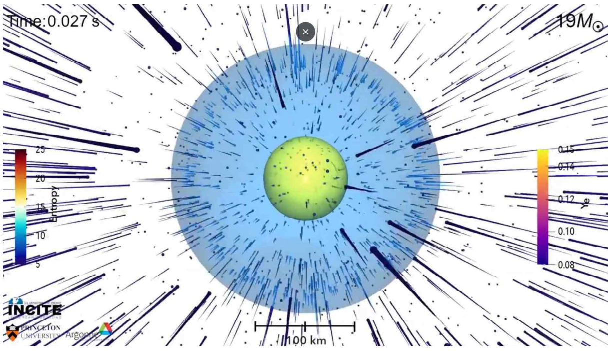


Figure 6. Scientific visualization by Princeton University.[7]

"Supernova" aims to artistically and performatively present this astonishing phenomenon, based on the authors' interpretation by applying cinematographic camera techniques to obtain cinematic and narrative scenery within the context of Audiovisual compositions. This piece comprises three-movements highlighting the sequential phases; before, during, and after the explosion as follows:

- **First**, displaying the red giant star surrounded by the space objects at various angles.
- **Second**, artistically simulating the early phases up to the supernova explosion
- **Third**, the birth of a neutron star

Niagara particle system[8] is employed to create the space objects and is applied into three different game levels to simulate the sequential phases. Additionally, to establish synchronicity with the audio, the audio-reactive method is partly implemented on several behavioural parameters of Niagara and lightings.

Furthermore, to execute these complex interactivities in real-time, a dedicated system is developed that enables the performer to configure the necessary parameters simultaneously across varieties of software; Unreal Engine and Max/MSP (see live interactive design). [9] [10]

Cinematographic Camera Techniques

Camera systems are essential elements in film production to embody narrative ideas and cinematic views by applying cinematographic camera techniques. In 3D computer games, this system functions to present the character's view at best position angles accurately, generally when *First-Person or Third-Person* shooters perspective is utilized. One existing example is proposed by Ting-Chieh Lin et al., 2004, which encapsulates cinematic camera techniques into camera modules corresponding to the player's perspectives.

This practice-led research attempts to implement these camera techniques to distinctly present the visual elements of an audiovisual composition "Supernova."

These techniques are:

- Zoom; moving the viewing perspective closer or further from the subject.
- Pan; moving the camera view horizontally, similar to audio panning (L/R).
- Tilt; vertically moving the camera view similar to panning.
- Auto/Manual Focus; adjusting the camera focus on a specific object.
- Rotation; rotating around in a spherical radius on an object.
- Free-movement; Free-movement; the amalgamation of Pan, Tilt, Rotation surrounding the subject within a spherical domain.

Live Interactive Design

The performer's role during the show is to present visual elements of "Supernova" cinematically without leaving aside the other control aspects, particularly the audio components. Therefore, the live interactive system is designed to provide a flexible configuration of virtual cameras and audio parameters simultaneously through specific functionalities of software as follows:

- Max/MSP as a command hub that hosted audio files, and all information to manage all interactivity events in Unreal Engine.
- Unreal Engine to create virtual environments and executing camera procedures.

All the data workflows on Max/MSP are assigned over two procedures: incoming data of the Xbox gamepad and Max/MSP UI that loads on a secondary touchscreen display in presentation mode—giving the performer better surface control during the show (see appendix A).

Below is the process diagram of the interactive workflow:

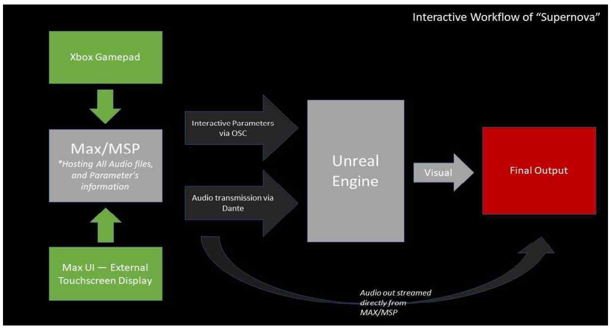


Figure 7. General Interactive Workflow.

Level Design

The three supernova processes are manifested within three different game levels (see appendix B). These levels are switchable alternately in real-time using the Xbox gamepad buttons connected to Max/MSP and deliver the setup information to Unreal Engine Blueprint (see figure 8).[11]

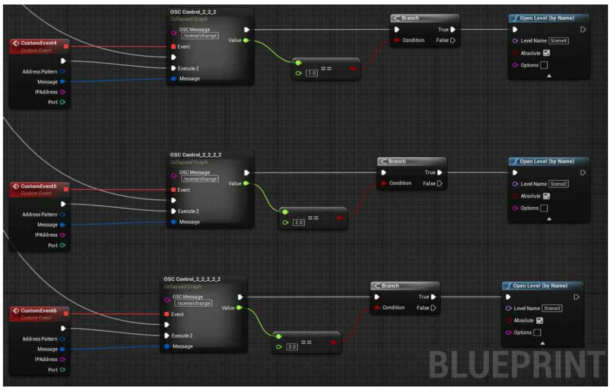


Figure 8. Blueprint system to control the game level changes.

Camera Workflow

The virtual camera parameters can be accessible via Unreal Engine Blueprint and controllable over two modes that correspond to the transmitted information from Max/MSP (see figure 9).

- Pre-sets mode; fixed view of specific camera techniques.
- 360 Moveable mode; 360-degree locomotion (position & rotation) control via Xbox rotary joysticks.

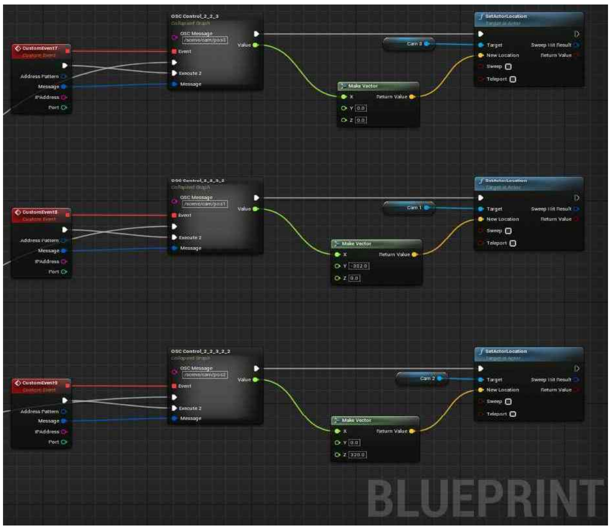


Figure 9. Blueprint system to access camara configurations.

The Pre-sets mode stored the cinematographic camera techniques and can be instantaneously activated when receiving incoming orders from the Max/MSP UI. Likewise, the 360 moveable mode allows the performer to obtain full access to the position and rotation locomotion within a spherical domain that can be configured by the performer using Xbox gamepad—rotary joysticks (see appendix C).

Audio Workflow

The music elements (audio files) are stored in a dedicated system built within Max/MSP to optimize the performer workflow when operating the camera modes. Accordingly, the performer can consecutively execute these audio files using the custom UI and real-time timecode on the secondary screen as guidance.

Subsequently, the executed audio files are routed directly as a final output and streamed via Dante Protocol[12] as data inputs for the audio-reactive operator inside Unreal Engine. The audio analysis tools are built using the Blueprint that functions to obtain certain audio information to set up Particle systems, and Lighting parameters in real-time; size and intensity (see figure 10 & 11).

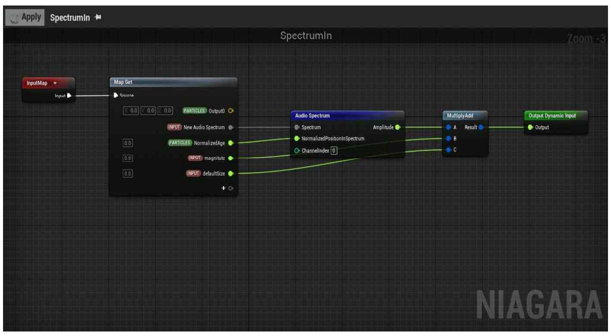


Figure 10. Blueprint system to acquire audio spectrum data.

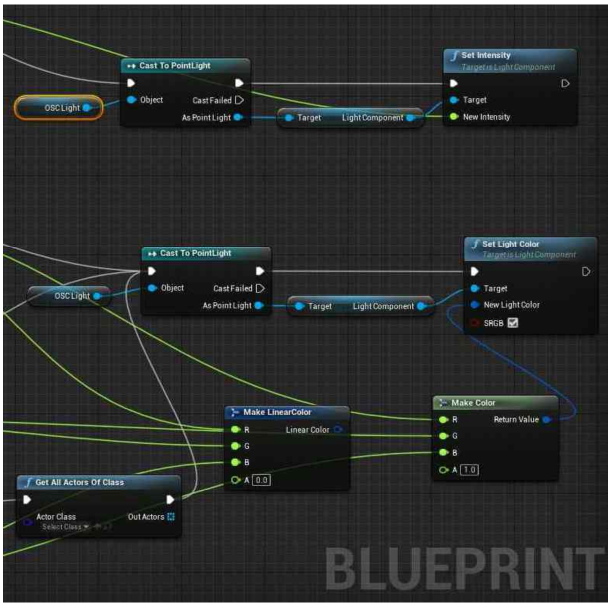


Figure 11. Blueprint system to configure lighting intensity and color.

Conclusion and Further Development

By utilizing virtual cameras as an ultimate way to present visual elements, composers can unfold new creative possibilities to compose and perform audiovisual compositions. Since this method is still relatively new and related to the development of computer game technology (game engine) or computer graphics in general, more creative potentials will emerge in the future.

Further development will focus on incorporating this camera method into virtual reality pieces, including adapting the VR joystick as system control through *3D user interface* design (slider) similar to what has been developed by PATCH.XR[13] but with different design concepts.

Due to technical limitations (i.e., OSC protocols and high CPU performances), several initial ideas were unachievable such as the real-time spatial audio synchronization with camera movements, multiple cameras usage (more than 3) and real-time manipulation of more complex behavioural particle systems.

Such features would help expand innovative possibilities for audiovisual composers and contribute to emergent immersive experience when presenting audiovisual compositions. Furthermore, hopefully this method may provide a meaningful resource for other composers/artists.

The audiovisual documentation, Max/MSP patch and Blueprint file can be found at https://www.patrickhartono.com/supernova

Acknowledgement

We acknowledge the Traditional Owners of the land of the Wurundjeri and Boonwurrung/Bunurong people and pay respect to their Elders and families. We also acknowledge all First Nations communities and their protocols of exchange and sharing of culture and connection to the land that informs this project.

References

Bennett, Joel/ Carter, Chis P. (2014). Adopting virtual production for animated filmmaking. *In Prakash, Edmond (Ed.) 7th Annual International Conference on Computer Games, Multimedia and Allied Technology* (CGAT 2014), 24-25 March 2014, Singapore.

Climent, R./ Pilkington, M./ Mesárová, A. (2016). *Exploring real, virtual and augmented worlds through "Putney", an extended reality*. Econtact.Ca. Retrieved September 29, 2021, from https://econtact.ca/17_4/climent-etal_putney.html Retrieved September 10, 2021.

Hamilton, Rob. (2013). *ECHO::Canyon*. Stanford.Edu https://ccrma.stanford.edu/~rob/portfolio/echocanyon/ Retrieved September 10, 2021.

Lin, Ting-Chieh/ Shih, Zen-Chung/ Tsai, Yu-Ting. (2004). Cinematic Camera Control in 3D Computer Games. *In Proceeding of WSCG SHORT Communication papers proceedings WSCG 2004:* 289-296. Plzen, Czech Republic.

May, S. (2015). *What is a Supernova?* https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-supernova.html Retrieved September 10, 2021.

The early phase of a supernova explosion of a massive star in three dimensions. (June 23, 2020). [YouTube]. https://www.youtube.com/watch?v=J61CjLDhm8U Retrieved September 10, 2021.

Wolf, M. J. P./ Perron, B. (Eds.). (2013). *The routledge companion to video game studies*. ProQuest Ebook Central https://about.proquest.com/en/products-services/ebooks-main.

[1] "Test Pattern" by Ryoji Ikeda is one famous example of audio-reactive works, https://www.ryojiikeda.com/project/testpattern/, Retrieved September 10, 2021.

[2] https://youtu.be/0dZ3K8ClZII, Captured September 9, 2021.

[3] https://vimeo.com/109376169, Captured September 10, 2021.

[4] Xbox is a video game company established and owned by Microsoft.

[5] https://www.unrealengine.com/en-US/blog/forging-new-paths-for-filmmakers-on-the-mandalorian, Retrieved September 10, 2021.

[6] https://www.youtube.com/watch?v=cceau0-2-ew, Captured September 10, 2021.

[7] https://www.youtube.com/watch?v=J61CjLDhm8U, Captured September 10, 2021

[8] Niagara is a visual effect system of Unreal Engine, https://docs.unrealengine.com/4.27/en-US/RenderingAndGraphics/Niagara/Overview/, Retrieved September 10, 2021.

[9] Unreal Engine [UE4] is a complete suite of creation tools for game development, simulation, visualization, etc., https://www.unrealengine.com/en-US/faq, Retrieved September 30, 2021.

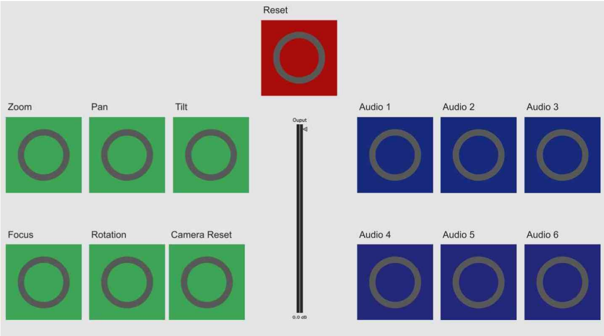
[10] Max, also known as Max/MSP/Jitter, is visual programming language for music and multimedia, https://en.wikipedia.org/wiki/Max_(software), Retrieved September 30, 2021.

[11] Visual scripting system in Unreal Engine like Max/MSP.

[12] Audio distribution system over IP (Internet Protocol) that enables to inter-applications transmission.

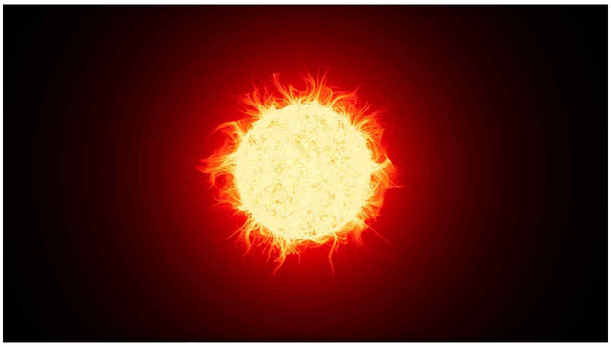
[13] PatchXR is a Swiss-Danish software company focused and developed Virtual Reality Musical Instrument/Environment using blocks called PatchWorld, https://patchxr.com/about/, Retrieved September 30, 2021.

Appendix A: Surface Control

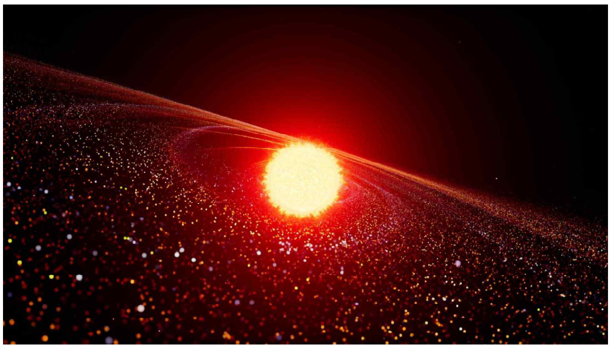


Max/MSP User Interface on secondary touchscreen display.

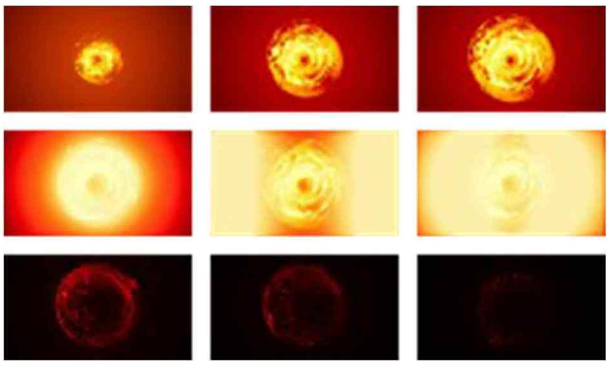
Appendix B: Game Levels



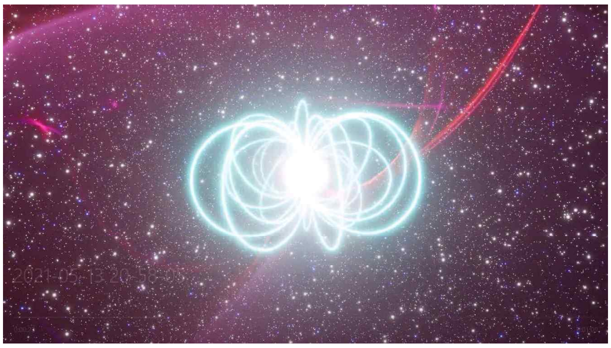
Level 1: Super red giant stellar.



Level 2: Super red giant stellar during early phase of supernova.

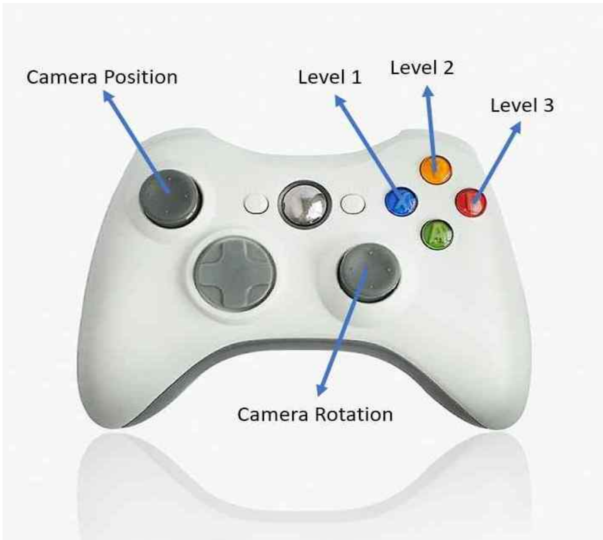


Sequence of supernova explosion.



Level 3: The birth of a neutron star.

Appendix C: Xbox Gamepad



Xbox Gamepad Parameter Assigned.

Transformation into Artificial Intelligence: Aesthetical Changes in the Roles of the Composers and Performers with regard to the Score.

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The appearance of the score in the historical musical context was to a large extent connected with the need for an additional source of preservation, with the possibility of creating an external object of musical memory, which in the future would not depend on the life expectancy of people or on possible weakening (up to the disappearance) of oral traditions.

The mechanism of written preservation of music as a score has undergone many modifications throughout its history. Reading the score without singing along / without playing music most likely happened in parallel with the acquisition of the skill of reading to oneself. Notation, on the other hand, developed towards greater detail, the number of parameters indicated in the score increased, the graphic complexity increased, and more and more different types of musical notation of the same thing appeared. In addition, the score has become overgrown with complementary materials (from introductory pages explaining the notation to many books and other sources (from the composer's sketches to preliminary versions of the music in midi or audio sound and demonstration videos) explaining how to understand and to play one or another score).

Nevertheless, it seems that the more we try to overcome the insufficiency of the score, the more clearly the problem of the lack of individual knowledge, as well as the incompleteness and imperfections of this type of notation and of preserving this music, becomes apparent. It is possible that this is what prompts us to search for new solutions in creating an external object of musical memory, resorting more and more to the help of modern technologies.

The emergence of the roles of composers and performers in the history of music is largely associated with the acquisition of a personal "I", the culmination of which can be considered the famous phrase by Rene Descartes "Cōgitō ergō sum" ("I think, therefore I am"). The corresponding cultural context gave rise to the subject and subjectivity, consciousness and the inner world of an individual, which allowed, in particular, the composer and performer to gradually become non-anonymous personalities and to place musical interpretation on a certain kind of pedestal, thereby exerting a strong influence on the dominant type of music of that time.

The very possibility of many individual interpretations of a musical work correlated with the idea of many completely different inner human worlds, with a wealth of expressions, feelings, emotions that have an infinite number of shades. And if in the 19th century during the period of romanticism there was no doubt about the value of such an approach to music, then the 20th century changed the attitude towards the score towards the importance of its technical characteristics, and composers such as Igor Stravinsky and Karlheinz Stockhausen asked the performers not to interpret their music, and play only what is written.

Moreover, the emergence of musical audio and video recordings has led to the fact that a significant part of the continued existence of music began to depend on a fixed (and even corrected) studio recording result, rather than on the spontaneous manifestations of musical "interpolations" during a live concert. Also, the emergence of such genres as electronic, concrete and computer music had a significant impact, making the priority attention to technical characteristics.

If we consider what is contributing to the development of the cultural context of the early 21st century, then it is directly related to the large-scale proliferation of personal computers and other devices (as the personal "I" once spread), where communication with the Internet has become much more necessary for many people than to search for connections, for example, with a divine source through religious practice, and the concept of the subject has shifted towards the creation of an avatar with his own world or worlds. The procedure of virtual inscription and Internet publishing has become firmly established with the idea of existence and presence in the world, including in the world of music. And in this world it becomes more and more difficult (to the point of impossibility) to distinguish music written by a person from music created exclusively by a computer and its algorithm.

In the history of computer music, we have come a long way from the early days of Lejaren Hiller's “Iliac Suite” (1959) and Xenakis' “ST” pieces of the 1960s. When the computer had a more modest role of composer assistant, there was no question of who was the composer of the work. Even in those days, there was a dispute between Xenakis and French composer, Pierre Barbaud, as to whether to call a piece “computer music” if the composer had the right to change the result that the computer gave. Xenakis argued that the human composer must take responsability for the work ultimately and that this gave the composer the duty to not just accept what the computer generated. Clearly, for Xenakis, the computer was an assistant and not the composer.

The former skepticism about the abilities of various kinds of algorithmic programs was gradually replaced by a frank admission that today the result of these constantly learning machines can not only be comparable to that of a human, but in some cases can exceed the capabilities of a person by a huge amount. And even if we do not believe that it is possible to literally find a computer "mind" in technical innovations spreading today, nevertheless, from a linguistic point of view, in modern language we attribute "intelligence" to various technical devices (smart home, smart refrigerator, smart TV, smartphone, smart car...), as once, with the help of language, a person began to attribute to himself the presence of consciousness and reason.

The above context has had a direct impact on the concept of contemporary scores, as well as on the roles of composers and performers today.

The degree of digitalization of the process of creating a musical composition is far from limited to the transition to a computerized musical score set with listening to samples. A huge variety of all kinds of music programs, from applications for determining musical pitch and ending with algorithms that produce an almost finished musical result, are in such a digital environment where there are digital notebooks for sketches and ideas, where through social networks, or on a separate website, the composer can talk about their writing process, where rehearsals with musicians can take place through the exchange of audio recordings and messages or via video communication, and when the composition is ready, the Internet environment transforms it into content, even if we think of music as not reducible to Internet terminology.

The score is technically presented today by musical programs as a set of measurable quantities (starting with pitch, duration, dynamics, tempo, size, fingering, articulation and ending with specific designations of modern techniques for playing musical instruments), which we introduce by choosing their values.

Moreover, having chosen the musical instruments and the timbres we need, we can listen to the sound of the score in a format accessible to the program. On the one hand, such a musical environment, which has become familiar to many composers, has supplanted the manuscript of the score with its manual labor, lack of sounding in digital mode, and with possible difficulties in deciphering the handwriting (in parallel with the extremely rare handwritten letter).

On the other hand, music programs are not the equivalent of a "blank slate", since they already contain typed program code with prepared capabilities and limitations, into which the composer immerses himself, having learned to use them, and on which he is more or less dependent.

The historical transformation from the unmeasurable to the measurable (which has happened, for example, with the concepts of time and space) receives its technical support for measuring a multitude of musical parameters with strict precision. The suppression of the roles of composers and performers today occurs primarily when they are trying to compete with the autonomous computer algorithm, but by this they only prepare their own obsolence. Whatever the limitations of the human composer/performer, they also have their particularities which distinguish them from computer algorithms.

Musical artificial intelligence as a form of the maximum possible independence of a trained machine from a person already has metahuman potentials of working with a million musical parameters per second at the same time, based on the analysis of all available Big Data, which has access to all existing musical scores, recordings, books... in a constant update mode. The computer “hearing” of such a device has the potential to recognize the smallest changes in any musical parameters, as well as to determine the source of the sound itself and its localisation in space, the technical characteristics of the microphones used in recording it and other information.

If a certain motive or melody is given, then obtaining samples of its use in music is likely to be a matter of a few seconds of searching the appropriate database. It is also possible to imagine that musical external memory and music creation / saving from the score will become advanced in its music modeling / simulation, where musical parameters will be processed by combined neural networks and other systems. As for the speed, the emergence of new music can be a matter of a few seconds (or even less), revealing an increasingly obvious contrast with the "slow" human artist.

The aesthetic value of musical compositions begins to undergo inevitable changes, because even when a person interacts with increasingly complicated algorithmic programs, we have already stopped, or are no longer understanding, how it actually works and why the algorithm produced this or that result. We cannot ask, for example, the question "What did the composer want to say?" to a self-learning music machine. Also, we will not come to the dwelling of this machine to feel its atmosphere of life, its spirit, how it lives, what inspired it, and what kind of life drama is associated with writing this or that musical composition. Therefore, we will ask other questions, studying the history of the creation of this algorithmic program, on what it was trained, what its characteristics are, and we will also try to find value and even beauty in the simulation of certain human feelings.

From the point of view of the use of musical compositions, almost or completely created by musical artificial intelligence, such questions as authorship (to whom does the composition really belong?) and ethical restrictions (can musical artificial intelligence be limited by ethical laws accepted by man?) will need to be considered.

The modern computer music automaton is both an ideal and a symptom. Reflecting on this topic, I wrote a piece called "Transformation into Artificial Intelligence" for the French duo “La Quantité Discrète” (baritone and viola da gamba). In this piece, the voice of the baritone, for example, is far from limited by the timbre of the traditional baritone. The vocalist is invited to sing with a male voice, a female voice, and a kind of unisex timbre. In addition, there are indications of imitation choral singing, a boyish soprano, a low growl of an old man, and a mechanical voice that sounds like a talking machine. But these are not the only timbres used in this piece. The voice itself goes beyond the voice timbre. The score is written to perform the voice of the trumpet, saxophone, flute and viola da gamba. The voice is also involved in the producing of noises, such as the noises of electronic devices, wind sounds, whistles, squeaks, glitches and the creaks of iron.

References

Descartes, René. (2004). [1637]. *A Discourse on Method: Meditations and Principles*. Translated by Veitch, John. London: Orion Publishing Group: 15. ISBN 9780460874113.

Hiller, Lejaren A./ Leonard M. Issacson. (1959/1979). *Experimental Music: Composition With an Electronic Computer.* McGraw-Hill. New York. ISBN 978-0-313-22158-3.

Serra, Marie-Hélène. (Winter 1993). *Stochastic Composition and Stochastic Timbre: GENDY3 by Iannis Xenakis*. Perspectives of New Music. 31(1): 236-257.

Barbaud, Pierre. Website of the association Pierre Barbaud. http://www.associationpierrebarbaud.fr/biographie-en.html

Sekatsky, Aleksandr Kupriyanovich. (2019). Sacrifice and meaning. *Where am I: on the new personology of presence*(Edition in Russian): 312-354. ISBN 978-5-6044906-0-0

Krashenko, Olga. (2013). *River of Thoughts. To think is already to sound*. (unpublished).