Auragami

Unfolding Stereo Audio for High-Density Loudspeaker Arrays

John Tanner Upthegrove

14 May 2019

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Fine Arts

in

Theatre Arts

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May 14th, 2019

Blacksburg, Virginia

Keywords: spatial audio, 3-D sound, ambisonics, sound design, digital audio, signal processing

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ABSTRACT

As a critical complement to immersive music, especially in virtual and augmented reality, demand for high-density loudspeaker arrays (HDLAs), consisting of 24 or more individually addressable loudspeakers is increasing. With only a few dozen publicly accessible systems around the world, HDLAs are rare[1], necessitating artistic and technical exploration. The work presented in this thesis details the culmination of four years of aesthetic and technical practice in composition and sound design for high-density loudspeaker arrays as an attempt to solidify existing standards and posit new practices. technical achievements include a pipeline to create repeatable and portable spatial audio mixes across arbitrary loudspeaker arrays, rapid spatial sound prototyping, and digital audio workstation workflow for 3-D soundscape creation. Aesthetic explorations have resulted in a distinct compositional voice, utilizing spatial audio systems as an instrument. Compositions specific to one venue may take advantage of the unique characteristics of a venue, such as loudspeaker layout, loudspeaker quantity, and room acoustics. The detailed graduate projects from 2015 to 2019 exemplify technical and compositional achievements in the exploration of the potential for HDLAs.

[1] "List of permanent Ambisonic playback systems - Wikipedia." https://en.wikipedia.org/wiki/List_of_permanent_Ambisonic_playback_systems. Accessed 4 May. 2019.

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GENERAL AUDIENCE ABSTRACT

How does one begin making music for over 100 loudspeakers? This thesis examines the creative and technical practice of a graduate student to make music and theatrical sound design for audio systems that have 24 or more individual loudspeakers.

Acknowledgements

For the countless moments of encouragement and love, **Molly Upthegrove**, I could not have done this without you. You inspire and enable me to be my best. I admire you as an artist. I love you.

Barbara and Bill Upthegrove

Cindy and Danny Barnett

Charles Nichols

Chris Russo

Randy Ward

Mike Roan

Ben Knapp

Holly Williams

Melissa Wyers

Joe Court

Bill Barksdale

Zach Duer

Ryan Baker

Steve Ellison

Richard Bugg

Trey and Fernanda Spruance

Stephen Vitiello

Doug Witney

Rob Gainer

Gustavo Araoz

Laine Goerner

Ryan Hasler

Bob Katz

Hunter Menning

For **Fiona Upthegrove**: I hope your curiosity never ends.

Contents

Introduction

Theatres have been utilizing spatial audio for decades to immerse and dazzle audiences. It is common practice in theatre to ad-hoc install loudspeakers where a sound needs to be. The music, cinema, gaming, and entertainment industries have been standardizing multichannel audio systems[2] [3]. These disciplines have converged with questions about standardizing practices to empower artists for spatialized audio, with some emerging formats[4] [5] [6] taking hold as industry standards.

When I met Dr. R. Benjamin Knapp, Virginia Tech's Institute for Creativity, Arts, and Technology's Founding Director, one of the first questions he posed to me was, "wouldn't it be interesting to make music in a room with 40 loudspeakers?" I agreed, but my background in two-channel, stereo audio studio recording left me wondering about the possibilities and complications. Only a year later, I was part of an innovative team[7] of faculty and consultants designing and deploying a spatial audio system for one of the largest black box theatres on the east coast of the United States with 140 individually addressable loudspeakers. Most facilities like this have the affordances to rig loudspeakers and other theatrical equipment just about anywhere in the room, but few retain installations like this on a permanent basis. This specialized theater, the Cube, enables a unique type of aural research and arts practice. Depending on the staging, the Cube is large enough for 120 audience and a stage for performers creating a social listening and experience circumstance. The addition of an entire new dimension of sound possibilities raises questions such as listener orientation and leveraging technology to create new aural work. These adaptations combine studio practice with live sound techniques into a new kind of hybrid experience that includes programming.

The pieces began to come together when Dr. Charles Nichols, Assistant Professor of Composition, Creative Technologies in the School of Performing Arts Department of Music, introduced me to visual programming. I discovered the possibilities of using code to create art. This kind of real-time programming offers the immediate gratification of music creation with the boundless freedom of code to generate art.

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[2] "Surround sound - Wikipedia." https://en.wikipedia.org/wiki/Surround_sound. Accessed 5 May. 2019.
[3] "22.2 surround sound - Wikipedia." https://en.wikipedia.org/wiki/22.2_surround_sound. Accessed 5 May. 2019.
[4] "Dolby Atmos - Dolby Laboratories." https://www.dolby.com/us/en/brands/dolby-atmos.html. Accessed 5 May. 2019.
[5] "Spatial Workstation – Facebook 360 Video." https://facebook360.fb.com/spatial-workstation/. Accessed 5 May. 2019.
[6] "Wwise Spatial Audio | Audiokinetic." https://www.audiokinetic.com/products/wwise-spatial-audio/. Accessed 5 May. 2019.
[7] "Genesis of the Cube: The Design and ... - MIT Press Journals." 7 Feb. 2017, https://www.mitpressjournals.org/doi/abs/10.1162/COMJ_a_00394. Accessed 5 May. 2019.

The Galileo Project

In the Fall of 2015, my first collaborative project as a graduate student featured Willie Caldwell and Ryan McHugh, peers from my Graduate Seminar class. Inspired by the Fluxus movement, we created *The Galileo Project* to explore interdisciplinary, experimental performance derived from crowd-sourced collaboration. The resulting work is a mixed reality environment that utilizes emerging digital technologies, spatial audio manipulation, interactive computer programming of sound and lighting, and a live actor. The project explores connections between audience, artist, and immersion by placing the audience in the same performance and acoustic space as the performer. One specific question we wished to explore--if an audience contributes to the content of a performance, is there more buy-in from the audience?

Figure 1 - Artistic Representation of *The Galileo Project*, Tanner Upthegrove

Design Choices

The Fluxus Movement[8] inspired two design choices for The Galileo Project. First, to democratize the creation of the work itself, we solicited input from an audience. Second, the Fluxus movement indiscriminately used everyday objects as art and artmaking process. We sought to normalize technology by having an android-like character, without a clear distinction between human and machine.

From our devised script, I chose to create a futuristic, cold reality. Inspired again by Fluxus philosophy that does not distinguish the human and the machine. The setting could be on a space vessel or completely fabricated inside a robot dream. Organic sounds, such as explosions, were not processed to keep a context of place, and all other sounds emphasize a synthetic nature or have artifacts of digital manipulation.

[8] "Manifesto I - George Maciunas Foundation Inc.." http://georgemaciunas.com/about/cv/manifesto-i/. Accessed 4 May. 2019.

From crowd-sourced material of text, poetry, music, and pop culture references, Caldwell and McHugh generated a script that follows a confused android-like persona interacting with an omnipresent expositor. We explored a live actor engaging with a recorded narrator by testing the script in readings. All the audio media submitted was used after digital manipulation in an audio workstation as mono tracks, then exported as mono audio files. I used combinations of pitch shifting, reversing, time stretching, bit crushing, amplitude modulation, delay and reverberation to transform submitted media to sound quite different from the source, but could still be recognized by someone familiar with the original material. Musically, I created a palette of sounds in different frequency ranges to create interesting layers that did not compete with the narrated voice. Dull, crinkly sounds sit well above the spoken range and added a science fiction spaceship ambience when spatialized and played back in different loudspeakers. Warbly sirens rotated around at different times, representing operational systems in normalcy and urgency when in conflict. A theme that emerged when designing was confusion and disorientation with a glimmer of something recognizable inside, if scrutinized. This aural dystopia parallels the representation of the uncanny valley[9] by the organic actor, whose android-like figure is juxtaposed with existential questions.

We planned the performance for the Perform studio, a 9m x 9m research lab which can comfortably seat an audience of 50 in proscenium style, is acoustically treated, and features 24 Genelec loudspeakers in two rings of 12. Controllable room lighting and ample power circuits allowed the use of theatrical lighting instruments.

Technical Implementation

Using the Max programming language, I set up a multichannel [sfplay~] object to play back individual tracks of sound effects and music, as well as the digital narrator, from the disk drive. An [adc~] object was used to route the amplified signal from the live actor with a lavalier microphone, which was then processed with added equalization and reverberation. I then spatially processed each track with the [matrix~] object, controlled by different panners, sometimes using randomization and other times, rate-controlled ramps. Some tracks were set up with simple panners that I controlled live with a Korg nanoKONTROL input device. The nanoKONTROL also controlled spectral processing, a technique which transforms digital audio in the time domain to the frequency domain for control of individual frequency bands[10], for some audio sources and some of the master lighting controls. Some spatialization was triggered by a master clock, such as a panner that increased the speed at which sounds moved around each ring of 12 loudspeakers at the climax of the performance, creating a spinning disorientation to parallel the narrative of the organic actor's virtual ship failing.

[9] "Uncanny valley - Wikipedia." https://en.wikipedia.org/wiki/Uncanny_valley. Accessed 4 May. 2019.
[10] Smith, J.O. "SPECTRAL AUDIO SIGNAL PROCESSING." https://ccrma.stanford.edu/~jos/sasp/. Online book, 2011 edition. Accessed 4 May. 2019.

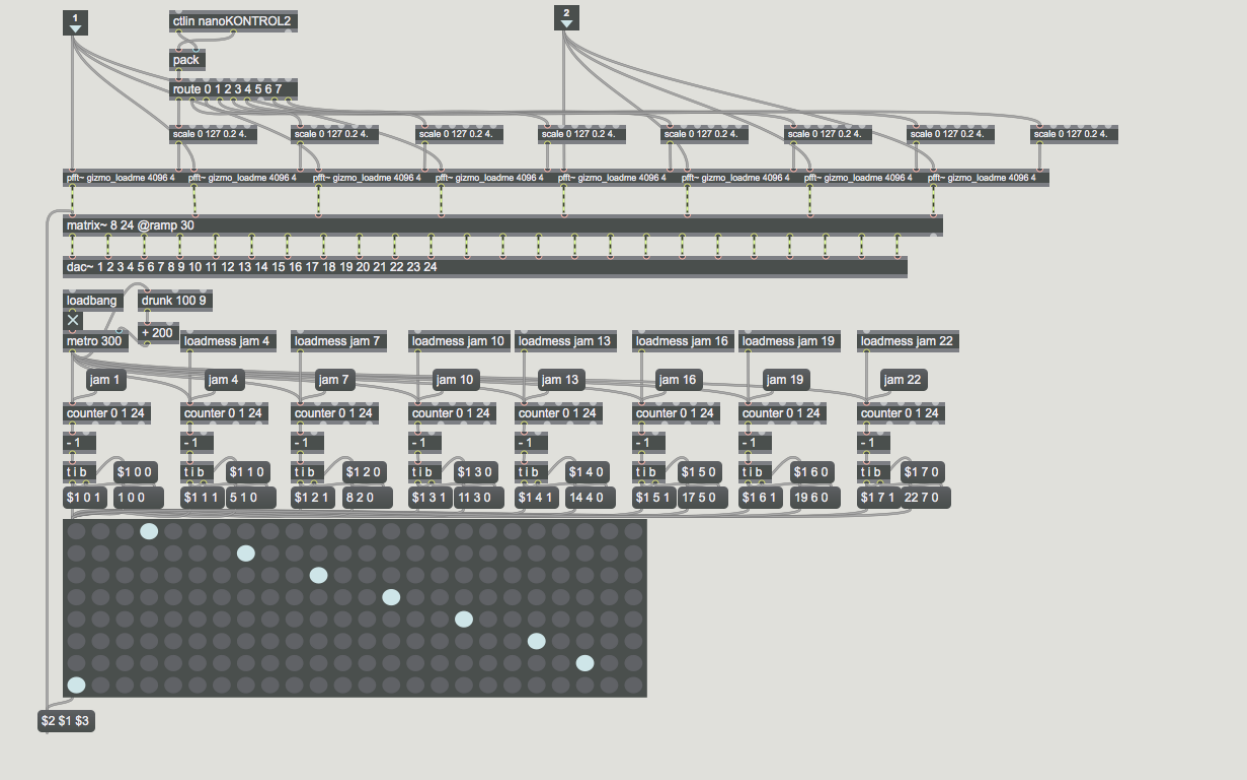

Figure 2 - Max audio panning code example, *The Galileo Project*, Tanner Upthegrove

Theatrical lighting surrounded the performer and was triggered by aural or planned events in the Max patch. Aural events took real-time digital audio data and analyzed pitch and amplitude to generate lighting data by transposing the pitches and amplitudes to colors and brightness. I chose specific colors when called for by the script. When not specified, I opted for colors and effects that I intended to match moods, such as strobing reds and whites during the fiery, cataclysmic introduction and ending. Planned events were triggered by time code. Some lighting effects were used to enhance the emotive state of the scenes. For example, traumatic scenes often had unsynchronized strobing to indicate disorientation. The narrator and live actor's audio always triggered lighting events tied to amplitude to add visual enhancement to the aural performance. The Max patch sent out red, green, and blue control values over a serial bus into a DMXIS interface which sent Digital Multiplex (DMX) control data to the lighting instruments with Olivier Pasquet's ENTTEC DMX USB Pro controller Max external objects[11].

[11] "dmxusbpro | Olivier Pasquet." https://www.opasquet.fr/dmxusbpro/. Accessed 11 May. 2019.

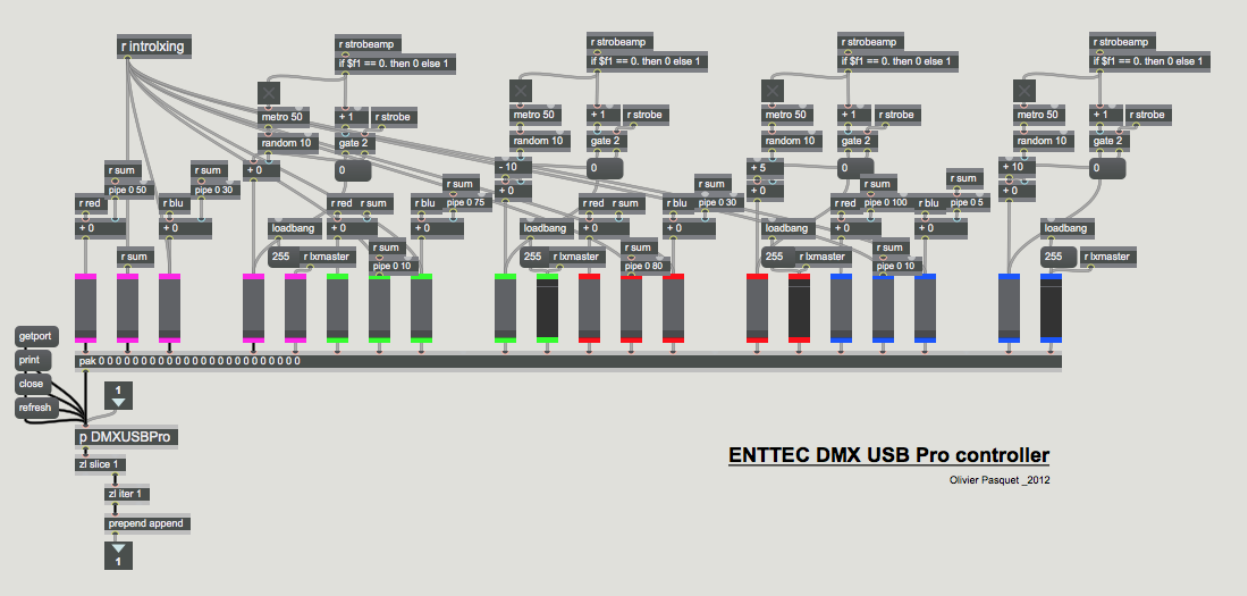

Figure 3 - Max code for lighting control, *The Galileo Project*, Tanner Upthegrove

Challenges

The media contributions from the audience provided an engaging challenge to tie disparate elements into one coherent vision. The context of a futuristic space vessel and a cyber-humanoid made my synthesized and digital manipulation of audio fit well with the script. The theatrical lighting was also important to enhancing the aural content by providing a visual anchor that matched sonic events.

As one of my first projects coded from scratch, many processes could have been simplified or made more efficient. I embedded all of the source audio tracks into a 12-channel audio file in one [sfplay~] object, which meant that changes to any of the audio files require re-rendering the 12-channel file. Moreover, while Max offers means to work with any kind of audio, this workflow is not native to Max, but rather digital audio workstations (DAW). DAWs allow for non-linear editing and processing of linear audio files. This is possible in Max with various transport methods, but cumbersome outside of editing a few files. Unfortunately, most DAWs were not intended for multichannel use beyond surround standards, such as 5.1 surround mixing.

The piece was designed to be performed in the Perform Studio. Spatial audio control was hard-coded to the number and location of loudspeakers in the Perform Studio so that perceived speeds of pans and ramp times fit the scale of the room. Significant time would be needed to adapt to a different set of loudspeakers and timings of spatial movement. For example, if moved to the Cube, the panning matrices would need to be re-created for the specific loudspeaker setup and panning timings changed to accommodate the difference in quantity of loudspeakers.

Conclusion

My first crowd-sourced composition, and collaborative project in spatial sound was informative. As a composer, I developed in my capacity for collaboration, and as a spatial-sound designer I learned some of the limitations of the hardware and of my coding knowledge. The final performance exceeded my original expectations and I think those in the room suspended disbelief for a brief period of time as we strolled through the uncanny valley together.

In an informal discussion with the audience after the performance, we found a commonality in audience feedback. Everyone who submitted content actively sought their submission in the performance and found interest in how their contribution fit within the greater narrative.

The Galileo Project was published in the proceedings of the IEEE VR: Mixed Reality Arts Workshop, and received the Bronze Award for Best Oral Presentation at the Virginia Tech Graduate Student Assembly Research Symposium. Also, *The Galileo Project* was presented at the 2016 Electroacoustic Barn Dance.

The Jury

"A movie without images: what does that look like? Or should we say, how does it sound?"[12] - Bruno Ruviaro

The Jury invites listeners to experience a Spaghetti Western soundtrack in the style of *Cinema for the Ears*[13]. Inspired by compositions by Ennio Morricone and Bruno Ruviaro, recordings of musicians and found sounds are produced into a five-minute fixed media piece. In films scores for *The Good, The Bad, and the Ugly* and *Once Upon a Time in the West,* Ennio Morricone utilized unique instrumentation, such as harmonica, jaw harp, and twangy electric guitar, when creating and recording film scores. Much of the foley, sound design, and unusual instrumentation Morricone innovated for his Western scores came from the necessity of a low budget[14].

I was inspired to create *The Jury* because I believe our society has a visual focus. Sound artist Stephen Vitiello describes this phenomenon with an example [paraphrasing]:

"Imagine you walk into a sound art installation. The room is completely dark except one polaroid photograph on the floor, illuminated by a single, focused light. Almost everyone will be drawn to the polaroid as the focal point, no matter how incredible the sound may be." - Stephen Vitiello

I chose to explore cinematic music and sound design that could tell a story without visual media.

The musicians who made *The Jury* possible were Jess Clough O'Reilly, violin; Alex Fowler, cello; Alex McLean, flute and alto flute; Charles Nichols, violin and electric violin; Mike Roan, acoustic guitars; Donna Thompson, soprano.

Design Choices

Dr. Nichols recommended I research existing works to inspire my choices. In particular, Nichols recommended Bruno Ruviaro's *Cinema for the Ears*. Ruviaro had created a film-length aural experience, complete with dialog, music, and sound design, mixed specifically for a 3-D experience in the ambisonics format. This reinforced my audio-only focus.

Stylistically mimicking Morricone, I wanted to include electric and acoustic guitars, orchestral strings, and flute for the orchestration of *The Jury*. This combination fueled a

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[12] "Bruno Ruviaro: Cinema for the Ears | Department of Music." 8 May. 2015, https://music.stanford.edu/events/bruno-ruviaro-cinema-ears. Accessed 4 May. 2019.
[13] "Cinema for the ears: Bruno Ruviaro expands the audio field ...." 18 Jun. 2015, http://peninsulapress.com/2015/06/18/bruno-ruviaro-cinema-for-the-ears/. Accessed 4 May. 2019.
[14] "Ennio Morricone Interview | Watershed." https://www.watershed.co.uk/articles/ennio-morricone-interview. Accessed 4 May. 2019.

lonely, arid Southwestern environment, which I then filled with designed sound to establish a time period reminiscent of the 19th century American West. Horse-drawn covered wagons on dirt roads open the piece, along with ominous raven caws, which set a mysterious scene. Flute and soprano frame a lonely soundscape with low, haunting melismas. During the first half of the piece, I envisioned a quiet town with shuttered windows where few dared to venture into the streets out of fear of bandits and scofflaws. Then, the Jury arrives, as intimidating as a pack of coyotes, to take on the lawlessness. The tempo increases, and the first strings and electric guitar blast in with aggression. A gunfight follows, with the ricochets bouncing around the room, and ultimately, a triumphant climax, heralded by fortissimo soprano, guitar, cathedral organs, fireworks, and cheering crowds.

I envisioned a performance that could be either a fixed media experience, similar to *Cinema for the Ears*, or with live performers. I opted to record all the parts to present a fixed media version at any time, and prototype spatial mixes. I engraved the score in MuseScore and recruited musicians to individually perform each part to a click track in the Perform Studio, with the exception of the violins and cello. To create a larger string ensemble than I had access to, I recorded the trio of violinists Charles Nichols, Jess Clough O'Reilly, and cellist Alex Fowler at the same time with two separate microphone arrays, with a minimum of two acceptable recorded takes. Moreover, Nichols, O'Reilly, and Fowler played both first and second parts. I directed Nichols, O'Reilly, and Fowler to assume different postures for different takes, such as assuming an angrier, aggressive stance for one take. By combining the different takes, microphone arrays, and direction to play differently for different takes, I had access to layers which I could process with equalization and bussing to composite into a single, larger ensemble. This process was inspired by composer and music production master Trey Spruance, as described in an interview in music production magazine Tape Op[15].

Technical Implementation

From previous spatialized pieces, I had mixed and committed batch audio stems to play back within a Max patch. Realizing the limits of my previous sound works, for *The Jury*, I innovated. I used the DAW Reaper to pre-mix the tracks with gain staging, compression, equalization, and a variety of time-based effects, like cascading delay lines set up in busses. I then routed each track out of the soundcard into the Cube's in-house Mac Pro with ethernet based Dante Virtual Soundcard[16], an audio over Internet Protocol that can stream up to 64 channels of audio from one computer to another receiver. The Max spatialization patch received individual sounds and only processed their spatialization and rendering to the loudspeakers. A series of 24 bus channels were set up in the patch with static locations, so that any track could be routed to any static bus, simulating a 24-channel loudspeaker array, like the experience of a large cinema audio system. In

[15] "Trey Spruance: Mr. Bungle and Secret Chiefs 3 | Tape Op Magazine ...." https://tapeop.com/interviews/85/trey-spruance/. Accessed 4 May. 2019.
[16] "Dante Virtual Soundcard | Audinate." https://www.audinate.com/products/software/dante-virtual-soundcard. Accessed 4 May. 2019.

Reaper, I mixed most stems as stereo pairs and routed them to busses. I paired all stereo busses as Left and Right on the Y axis. Stereo stems were then bussed to stereo pairs, with the intent that a phantom center would occur and panning between pairs would be apparent.

This was my first composition to use the ICST Ambisonics Toolkit[17], a software package developed by [names] that seamlessly integrates with Max. The ICST Ambisonics Toolkit affords computationally inexpensive, real-time encoding and decoding of high-order ambisonics format audio. By encoding individual channels of audio in a virtual acoustic space, it is possible to encode spatial music and decode to many configurations of loudspeaker arrays with a high degree of predictability in sound reproduction. In the case of composing for the Cube, one can direct each of the sound channels to a specific geometric location without having to articulate in code which specific loudspeaker to use, which becomes necessary when utilizing many input channels and addressing dozens of output channels. The ICST Ambisonics Toolkit also comes with a variety of built-in scripts to help make multi-object and multi-channel workflows simpler. One example uses the built-in auto-connection of Max objects with the [thispatcher] object. in Max, pre-designed pieces of code called objects connect together with a virtual patch cable, which sends data from one object to another. When scaled up to hundreds of objects, or objects that have hundreds of inputs or outputs, the ICST Ambisonics Toolkit scripts save a lot of time and offer powerful creative uses. I landed on the ICST Ambisonics Toolkit after trying a variety of free and commercial externals as the interfaces were minimalistic and clear. It is an ideal toolkit for making art because it is easy to use. The documentation made spatialization easy and worked immediately. Like the built-in scripts, other objects like the [ambimonitor] are computationally inexpensive and offer functions like simultaneous conversion of polar coordinates to the Cartesian format.

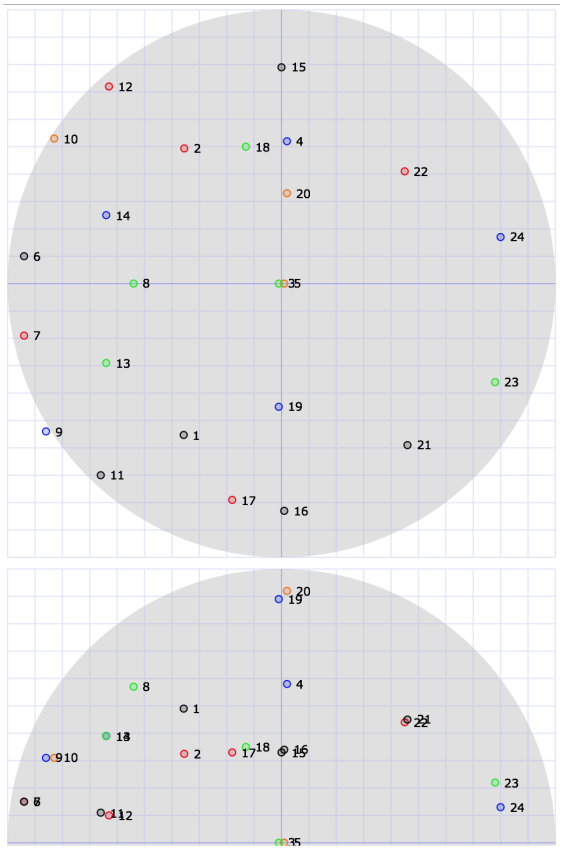

Figure 4 - Virtual sound object location representations, *The Jury*, Tanner Upthegrove

[17] "Downloads: Ambisonics Externals for MaxMSP | ZHdK.ch." https://www.zhdk.ch/forschung/icst/software-downloads-5379/downloads-ambisonics-externals-for-maxmsp-5381. Accessed 4 May. 2019.

Challenges

Though my composition for *The Jury* intended to showcase spatialization as an instrument, the technical interpretation proved to be a challenge. Time constrictions necessitated the use of static busses instead of designing trajectories for individual sound sources. The Reaper session that contained the music and sound design had 50 tracks, more than the 24 busses, so some tracks were mixed down to shared busses. The choice to use static busses simplified the technical arrangement, but it meant I did not have the option to dynamically move sound in the 3-D space. Moreover, the musical stereo pairs did not create the intended phantom center effect and were only perceived

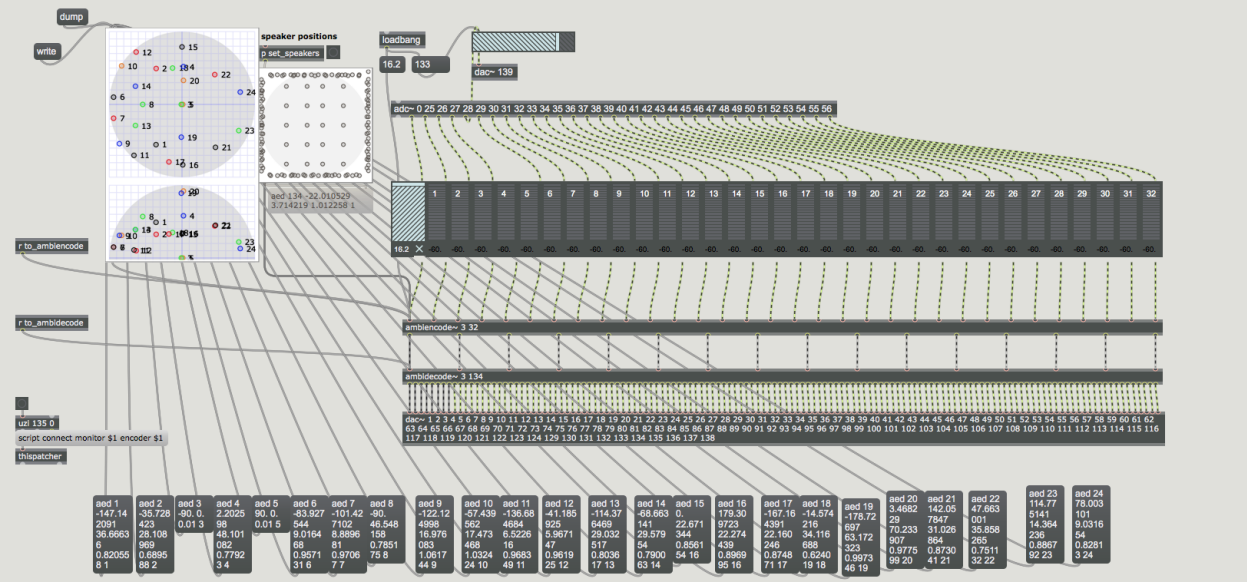

Figure 5 - Max audio decoding example, *The Jury*, Tanner Upthegrove

as point sources on the periphery. Further efforts to combine static busses and individual sound trajectories would resolve sounds as only coming from the periphery. For example, the gun fight would be more compelling if each gun shot and ricochet were separate sound objects, which could move in 3-D space.

Conclusion

Despite the limitations of static busses for the piece, I found that setting up stereo busses to diffuse stereo recordings was highly effective and could be an efficient way to implement stereo media without creating unique virtual sound objects for each individual sound. Stereo files with panning, such as the horse-drawn carriage, retain sufficient acoustic resolution even without automating virtual locations of individual point source objects. I also concluded that higher order ambisonics was necessary to achieve the localization of individual sounds in this composition. First order ambisonics did not provide the spatial resolution to pick out specific sounds, such as the individual acoustic guitars.

This project also led me to the conclusion that spatialization as an instrument would benefit from a more developed workflow between Max and Reaper.

Cube Fest: *Auragami*

My project for Cube Fest 2017 was inspired by the desire to make real-time changes to individual tracks and spatial automation. My workflow demonstrated that DAWs were superior for audio production and Max provided the extensibility to scale 3-D sound reproduction across almost any HDLA.

Over the summer and fall semester of 2016, I finished a prototype spatialization pipeline that enabled the compositions that I envisioned by creating a pathway between Reaper and Max that used automation envelopes, a common control feature in all DAWs. Automation envelopes represent control data over time. Drawing from audio mixing consoles that historically have motorized faders[18] which can store mixing movements, DAWs all have means to manually draw, automate, write, or record this information and apply it to almost any parameter inside the DAW. Reaper has two native features that made implementing a control data pipeline straightforward.

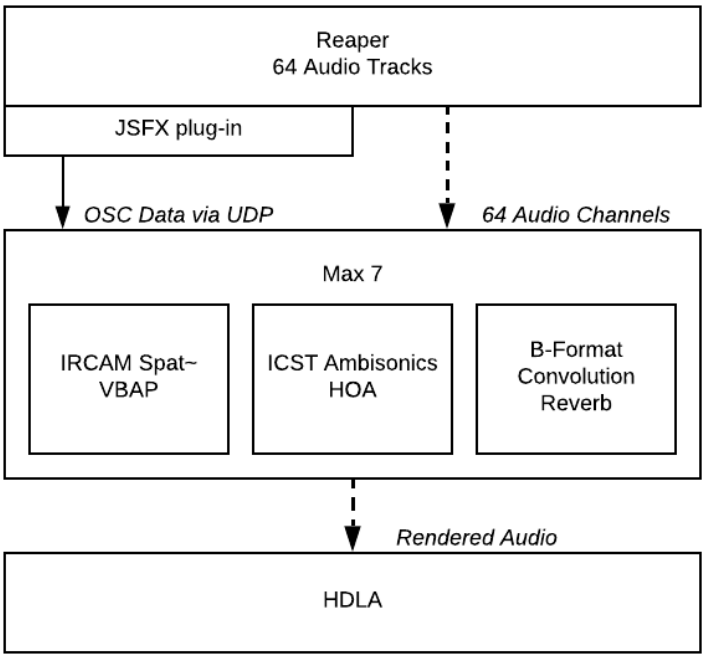

Figure 6 - Signal Flow Diagram for HDLA Spatialization, Tanner Upthegrove

First, Reaper's JSFX[19] environment is an open-source coding platform to create audio processing modules called plug-ins. I created a JS plug-in with four spatialization location parameters based on a polar coordinate system: azimuth, elevation, distance, and spread. Each of these parameters can be controlled by automation envelope, live control data input, or oscillators within Reaper. Each track with a mono audio source can host an instance of the spatialization plug-in, giving unique spatial control to each source.

Second, Reaper hosts support for Open Sound Control[20] (OSC) protocol, which is designed for real-time control applications for networked multimedia and computing. By modifying an editable configuration file for Reaper, I created custom definitions for what

[18] "Audio control surface - Wikipedia." https://en.wikipedia.org/wiki/Audio_control_surface. Accessed 4 May. 2019.
[19] "REAPER | JSFX Programming." http://reaper.fm/sdk/js/. Accessed 4 May. 2019.
[20] "Introduction to OSC | opensoundcontrol.org." http://opensoundcontrol.org/introduction-osc. Accessed 4 May. 2019.

data Reaper can send out, specifically selecting control parameters for the plug-in I created. Next, by choosing a computer on the same network, or the local host, the OSC formatted data from Reaper is streamed in real-time to a receiver in Max with User Datagram Protocol[21] (UDP).

Third, in Max, I parse the incoming data and reformat it to fit the required messages for the ICST Ambisonics Toolkit [ambimonitor] object. This object provides a visual representation of where each object is located in a virtual 3-D space. Cartesian coordinates are also possible, but not implemented in my JS plug-in. Data from the [ambimonitor] is then passed on to the [ambiencode~] object, also part of the ICST Ambisonics Toolkit. [ambiencode~] combines the data and audio signal to create real-time encoded B-Format audio, encoded as Higher Order Ambisonics (HOA). I also employed the IRCAM Spat[22] Vector Base Amplitude Panning (VBAP) 3-D panner, and formatted control data so the [ambimonitor] sends data to both panners simultaneously. VBAP and HOA panners are treated as busses and can be blended together.

Fourth, I innovated a new method to implement a master reverberation for HDLAs. Existing plug-ins for stereo and surround sound reverberation required too much computing power when scaled up to a HDLA the size of the Cube and lacked the capacity for ascribing sound localization or orientation. To create a more efficient master reverb that scaled to all HDLAs, I convolved real-time encoded B-Format audio with B-Format impulse responses (IRs). Convolution is the application of one function to another, which results in a new, convolved output. For the purposes of acoustic measurements, IRs are recordings of a volume excited by sound energy, completed when the energy dissipates. The convolution process was completed with the HISSTools Impulse Response Toolbox[23]. The resulting reverb is 3-D, computationally efficient, and scalable. Most impulse responses that I used came from the Open Acoustic Impulse Response Library[24] (OpenAIR), which were gathered from real acoustic spaces. Others were generated by Dr. Michael Ermann, Professor of Architectural Acoustics at Virginia Tech's School of Architecture + Design. Dr. Ermann and his students generated IRs which utilized my reverb pipeline and led to a study and publication in the 141st Journal of the Acoustical Society of America[25].

In parallel, I implemented a variety of methods to get audio data into the encoder, which requires both the control data and the audio data. Audio could be locally hosted in a Max patch with the encoder, or stream in. In the ideal case, the audio is hosted in the same Reaper file that uses the control data. In the early versions, I used SoundFlower and Jack for inter-software transport. Dr. Terence Caulkins, Associate for Acoustics,

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[21] "User Datagram Protocol - Wikipedia." https://en.wikipedia.org/wiki/User_Datagram_Protocol. Accessed 4 May. 2019.
[22] "IRCAM Forumnet | Spat." https://forumnet.ircam.fr/product/spat-en/. Accessed 5 May. 2019.
[23] "HISSTools Impulse Response Toolbox - GitHub." https://github.com/HISSTools/HISSTools_Impulse_Response_Toolbox. Accessed 4 May. 2019.
[24] "Browse the Auralization Database | The Open Acoustic Impulse ...." http://www.openairlib.net/auralizationdb. Accessed 4 May. 2019.
[25] "Subjective listening tests: Perception and preference of simulated ...." 9 June. 2017, https://asa.scitation.org/doi/abs/10.1121/1.4988111. Accessed 4 May. 2019.

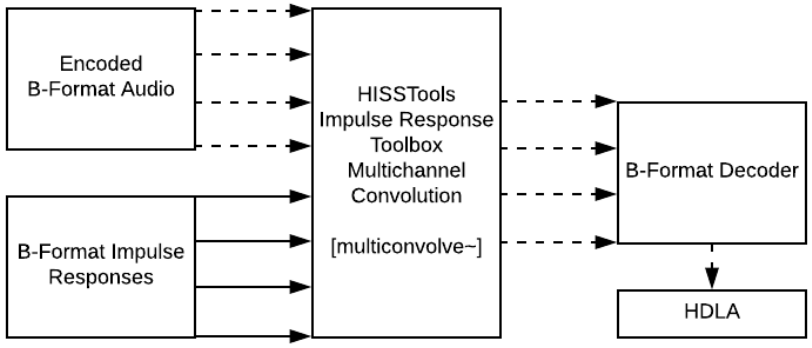

Figure 7 - B-Format Convolution Reverberation Signal Flow Diagram, Tanner Upthegrove

Audiovisual, 3D Sound Design at Arup, suggested using an RME audio interface with a hardware loopback, achieving 1ms latency. I currently use this method for reliable, low latency transport for up to 64 channels of audio. For streaming audio from a separate computer on the same audio network, I typically use Dante Virtual Soundcard, Dante hardware cards, or Multichannel Audio Digital Interface (MADI) for up to 128 audio inputs.

Design Choices

To put the pipeline to the test, I invited Trey Spruance to partake in a residency in the Cube to remix his stereo works for HDLA. An influential figure in San Francisco and metal music since the 1980s, Spruance is a composer, multi-instrumentalist, and audio engineer. Currently, Spruance is the band leader and composer for the multi-genre Secret Chiefs 3. I sought out Spruance specifically as I am familiar with his compositions, which have been formative in my aesthetics and professional life. Spruance amalgamates musical cultures with pieces like *Tistrya*, fusing Persian scales and time signatures with metal guitars. Through careful listening, one can hear the details and layering of hundreds of individual tracks mixed together.

Spruance expressed interest in unfolding the stereo recordings into multichannel listening experiences. To prepare, I asked Spruance to bring the original recording sessions or mono stems. A stem is a composite of multiple audio tracks, necessitated at the time by a limit of 64 channels. Spruance forwarded stems for *The End Times*, a composition with Wurlitzer electric piano, bowed saw, and santur. I prepared an example mix by statically placing some instruments together in different cardinal directions and creating automation for maracas to randomly move around the room. This presented a new possibility that the fixed stereo recordings could not offer; every time the HDLA version of *The End Times* is played it is slightly different. I chose to group strings into two large ensembles and used the VBAP spread capability to increase the number of loudspeakers used radiating from a center point, to give an impression of a larger size. I placed the other percussion in a central focus point, as the intended seating for audience was proscenium style. I intended for this session to be a template for Spruance to start with and get a feeling for what artistic expression is possible for 3-D sound.

The possibilities of unfolding stereo mixes immediately became apparent and engaging. Spruance was quick to adopt the workflow and subtleties of spatialization, enabled by the familiar automation envelopes.

Base Phive Futur Cossacks was the next piece to mix. Here I questioned, "How does the artist locate instruments in space if the ensemble has never assembled in real-life? How can previous ensembles be revisioned in new, provocative ways?" Having Spruance on hand, the audience's experience was tailored to the artist's 4th dimensional conception for the piece. Instrumentation included Raagini synthesizer, piano, percussion, glitch noise, and stringed instruments. As per Spruance's request, the piano and a delay effects were positioned at maximum elevation, so that the piano was heard to be overhead of the listener. Sound delay effects derived the artist's intentions by creating the sense of a corridor, or sound heard at a lateral distance from the listener. The bassy synths and glitch noises, from synthesizers or digital sound manipulation, were in panning busses on different phased timers on the listener's horizon, which unintentionally created ephemeral holophonic effects, giving the impression of the bass synth sounds moving through 3-D space.

The titles of all the pieces performed at Cube Fest:

The End Times	*Halloween*	*Bereshith*
Base Phive Futur Cossacks	*On the Wings of Haoma*	*The Western Exile*
The 4	*Exodus*	*Balance of the 19*
Tistrya	*Scorched Earth Saturnalia*	

Challenges

The biggest challenge was having enough time to do all the desired tasks. Despite the controlled environment of a studio, Spruance and I both agreed more time would have resulted in a better final concert.:

"To translate musical Ideas ever more faithfully to the real-world experience is not something you can just plug in and do. It requires intuitive aesthetic decisions at every turn, and as there are a billion new ways to go, there are often, paradoxically, a limited number of ways for those things to be 'right.'"

- Trey Spruance

We discussed the challenges and realities of making a live performance. With traditional live sets, it is common for artists to have little or no sound check and rehearsal time. If spatialized audio was to be employed, it would be difficult for a sound engineer to

spatialize the sound of a band in addition to normal duties. We agreed that the future of live spatial audio required a sound spatialization engineer that worked hand-in-glove with the sound mixing engineer. It would also be prudent for the spatial audio engineer to be familiar with musical content to make informed decisions.

Until this residency, I had not stress tested the pipeline. I found flaws in the networking, which caused undesirable audio artifacts. These artifacts caused a major distraction and lost time.

Conclusions

In the course of my growth and study of spatial sound, achievement of real-time changes to individual tracks and spatial automation became a priority. To achieve this goal, I created a prototype spatialization pipeline between Reaper and Max using automation envelopes. In examination of my achievement, I found a high fidelity between the artist's conception and the ultimate delivery of the sound spatialization techniques. In addition to presentation at Cube Fest: *Auragami,* the music of Secret Chiefs 3 was presented with this pipeline at an October 2018 performance at Envelop SF, San Francisco.

The Right of Way

"Hector Avalos was killed by a drunk driver as he rode his bicycle home from work. This beloved son, fearless boyfriend, and devoted friend was taken in the blink of an eye. In the aftermath was a quest for justice. Featuring interviews with Hector's family and friends and court transcripts, this immersive multimedia production looks at the evolution of our city streets over the last century. Who has the right of way? And how do we stop hitting and killing pedestrians and bicyclists?"

- Thomas Murray, Director and Playwright, *The Right of Way*

Fellow MFA in Theatre candidate Thomas Murray approached me as a collaborator and designer for his documentary play *The Right of Way,* offering my first opportunity to design spatial sound for a feature length theatrical performance.

Design Choices

Under the guidance of Dr. Charles Nichols in the Spring 2017 semester, Murray and I began a studio to explore sound design and to discuss the immersive elements desired for a Spring 2018 premiere in the Cube.

Thomas wove Hector's story with actual courtroom narrative, creative interstitial scenes, and testimony from experts. I wanted to derive all music from the text. Thomas provided hours of recorded interviews and I sought musical information from the interviews that might fit the live performance. As an experiment, I took one of the interview audio recordings and time-stretched the interview. I rendered out compressed and expanded versions, which I loaded into SPEAR, a spectral editing software. In studio, Dr. Nichols suggested several types of audio processing, and I chose SPEAR so I could visually seek patterns. I drew bounding boxes and envelopes to create frequency changes with the intent of having an ambient audio background with some rhythmic quality. I preferred the time-condensed files as the rhythm from the dialog was more interesting. I rendered out audio files from SPEAR and listened while reading the script. I felt that the frequency content of the rendered files was too similar to human speech, from which it was derived, and decided to add musical instrumentation to blend together. To accomplish this, I created a Max patch and took a copy of the time-stretched audio file that was not spectrally processed and synchronized playback with the spectrally processed file. I used the [fzero~] object to analyze frequency and amplitude, which I converted to Musical Instrument Digital Interface (MIDI) notes. The MIDI notes triggered glissando bells with the sforzando soundfont Virtual Studio Instrument (VST). The combination of the two sounds was much richer than the spectrally processed file alone by transposing the glissando bells an octave lower. The rhythmic content of the narration was

inconsistent, yet interesting, so I included a sine wave oscillator to generate a bass line with consistent timing as a focus point.

As the script called for *Daisy Bell* by Harry Dacre and *Route 66* by Bobby Troup for interstitial scenes, I collected MIDI versions of each song, so I could rearrange them to fit the timing of the scenes.

In parallel, I started collecting and creating sounds for known cues, such as gavels for the court scenes, ambient city sound, and dings to simulate Facebook messenger. I also completed an immersive sound moment for the top of the play in total darkness. I designed a scene to put the audience in Hector's perspective the night he was killed by using recordings to simulate riding a bicycle through Chicago streets. The familiar joy of pedaling a bicycle and changing gears is a constant sound. Occasionally, a massive vehicle whizzes by to demonstrate the power difference between a human on a bike and a car. The solitude of being on a bike and constantly shaken by huge sounds is jarring. I used this effect to create drama and tension. To create an illusion of movement, I processed the sound scene with 3-D convolution reverb to simulate environmental changes between open air streets and Chicago viaducts. I used two different impulse responses from a tunnel[26], which is similar to the viaduct where Hector was struck. The scene culminated with an oncoming car crashing into the bicycle, with a sequence of tire screeches, thuds, glass crashing, bike parts flying, and a body rolling. Intentionally gruesome, I followed the police reports to reconstruct what happened.

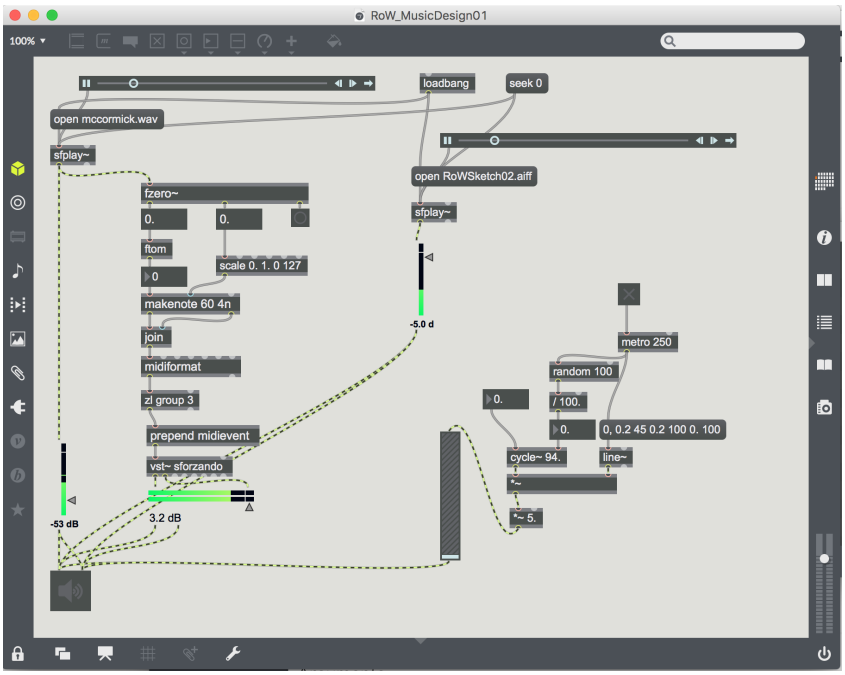

Figure 8 - Max code of music and sound design prototyping, *The Right of Way*, Tanner Upthegrove

After attending the first reading in Theatre 101, I learned a lot about the direction I needed to take as a designer. The play needed more realism and subtlety in the music than what I had derived from the text. I composed *Ghostbike* for piano which conveyed the steady pedaling of a bicycle, similar to the sine wave oscillator in the previous music design. I was careful to employ my recent gleanings from graduate studies, like the value of minimalism, as in the careful quiet of

[26] "Railroad tunnel - Purnode's Tunnel | The Open Acoustic Impulse ...." http://www.openairlib.net/auralizationdb/content/railroad-tunnel-purnodes-tunnel. Accessed 5 May. 2019.

Harwood's *The Dresser*[27]. It was important to step back the music design and let the actors tell the story.

To prepare for the next rehearsal and reading in Atlanta, I finished creating or gathering sound effects. I created a soundboard for the stage manager to operate for rehearsals.

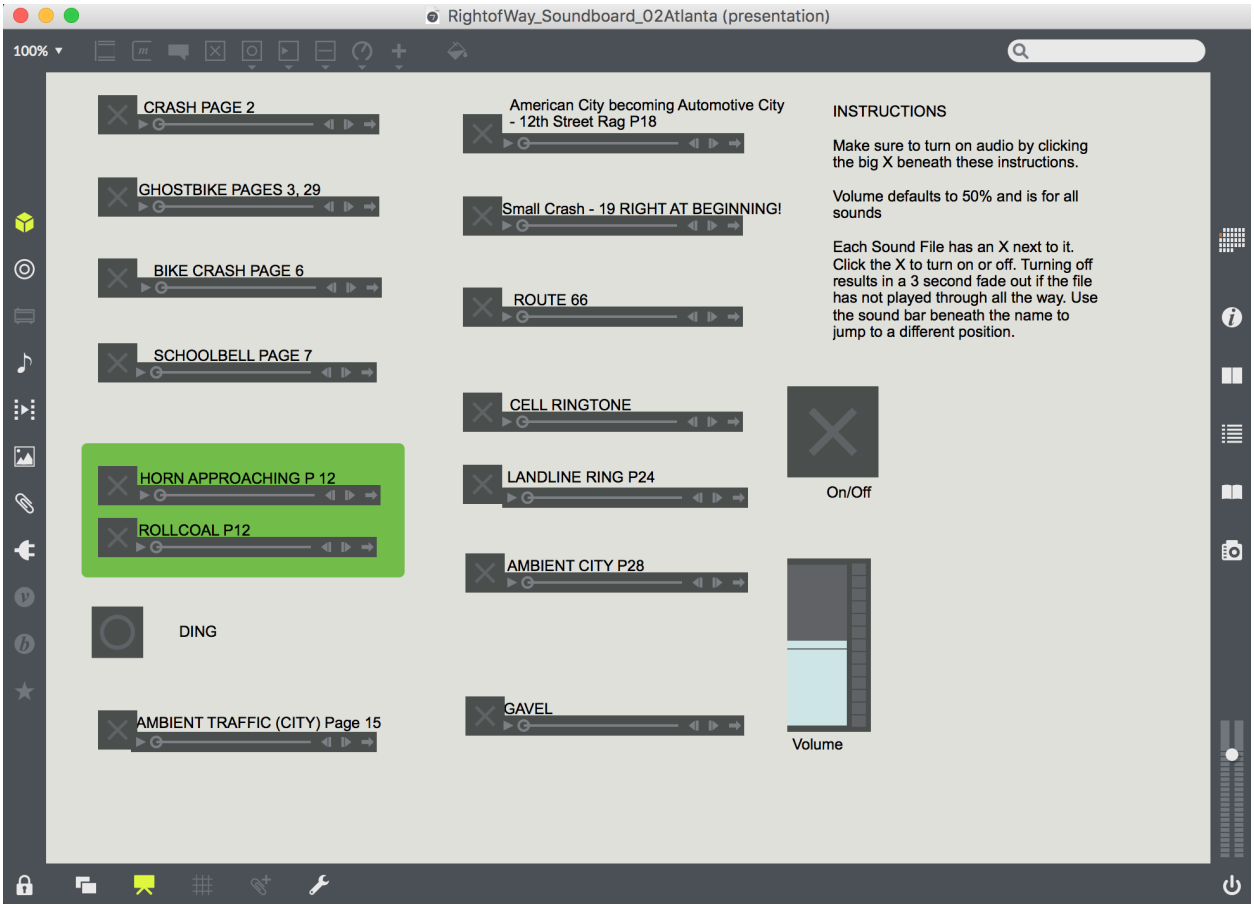

Figure 9 - Max soundboard, *The Right of Way*, Tanner Upthegrove

Another reading in Washington, DC brought more revisions to the script. To this point, most audio cues were literal and only the timings changed along with script revisions. Moreover, all sound was presented in stereo. At the end of the semester, Thomas and I presented a reading with sound design for ICAT Day in the Cube. The most spatially complete event was the crash sound design at the top of the play. The 3-D reverb in the HDLA brought the design to life by giving spatial context to Hector's perspective with real acoustics. The cars that whizzed by now came from opposing directions in traffic, just as they would in reality. The composite of sound effects for the crash was broken out so that the crash audio converged in the center, and the events that unfolded were spatially distributed to different points in the room. I took the other audio cues and added spatialization pertinent to the direction from the script. For example, the Facebook messenger scene has two actors on opposite walls. The audio cue of receiving a message was local in the venue to the recipient.

[27] "The Dresser - Wikipedia." https://en.wikipedia.org/wiki/The_Dresser. Accessed 5 May. 2019.

Moving forward to Spring of 2018, Thomas made several excellent changes to the script to make the play more concise and coherent for the March premiere, necessitating a revision of sound design. We devised four thematic scenes for sound design as the play now moved more quickly between scenes. The first scene type was Hector's story. The dialog from these scenes came from interviews of Hector's surviving friends and family. As these scenes describe the actual events of Hector's life, I chose to focus on realism for sound design. I found B-Format and stereo ambient city recordings as general canvases for each of these scenes, and added specific cues as called out by the scene. For example, during a potluck meal party, I simulated a distant boombox blasting music, localized sounds of plates, and had a specific cue call out for a sizzling barbeque. Another scene, a narrated memory by Ingrid Cossio, Hector's mother, recounted Hector's first bicycle. Ingrid remembers encouraging Hector to learning to ride his bike. At one point, Hector careens towards car traffic. Ingrid prevents a tragedy at this point in the story. As a sound designer, spatial audio made this scene gratifying because I took the literal sound cues and placed them where the actors were located in the room.

Court scenes were the second type of scene, comprised of the actual court records. These scenes were factual yet removed from time. To separate these scenes from other concurrent realities, I set up two shotgun microphones to capture the indirect, spoken performances of the actors. These live mics were processed in real-time with B-Format convolution reverb for HDLA to make the court scene sound like a cold, expansive cathedral.

The third type of scene was the interstitial scenes. These scenes were intended to break up the first two types of scenes, and at times, add levity to the play. Thomas brought on video designer Mordecai Lecky to tie in the expert testimony interviews with visual aids. Most of these scenes were for video and audio only, allowing actors time to transition to the next scene. For these scenes, my goal was to make the interviews as clear to the audience as possible, with little focus on spatialization. One benefit of an HDLA is that the loudspeakers are distributed with the audiences, so narration can be evenly distributed to all audience members.

The fourth type of scene was an audio immersion layer that could go on top of any other scene. When these events happened, I chose to make them very subtle suggestions, to make it unclear if the sound was real or possibly imagined. Murray was inspired to include sounds which were allusions by the characters, but not called out in the script. For example, in a court scene, a police officer testifies about what happened upon arriving at the scene where Hector was struck and died. The officer describes using the radio to call for help, which triggers the distant crackle of radio chatter. Similarly, the officer describes a recreation of the crash. Each step of the officer's description of the crash evokes a component of a bicycle-car crash. Towards the end of the play, Ingrid finds out Hector has been involved in a crash and sets out to find him with Hector's friends. When they arrive at the place where the crash transpired, Ingrid finds the blood of her son and is overwhelmed with grief. To emphasize Ingrid's world stopping, I used eight different recordings of traffic and time-compressed them, to suggest time was moving faster. The combination of all eight sped-up recordings was

disorienting, with Ingrid at the center of it all by spatially distributing the sounds equidistantly around her.

Seeking critique, I enlisted the attuned ears of Joe Court, Sound Design faculty in the School of Performing Arts at Virginia Tech at the time and now Assistant Lecturer of Sound Design and Technology at Ball State, who provided guidance and critique leading up to the play. Court suggested aesthetic changes, like sound levels, spatial placement, and design choices.

Technical Implementation

The sound and projections were programmed in QLab[28], along with OSC messages. QLab is a software application used in many theatres to organize and play back media and data. After sequentially programming a show in QLab, an operator can use the spacebar on a keyboard to transition between events called by a Stage Manager. The sounds were sent from the computer hosting QLab to the Cube in-house Mac Pro computer with a Max patch to encode and decode spatial audio. Live microphones were amplified and convolved in the Max patch. OSC messages from QLab triggered control data changes for scene changes. Examples of control changes include the changing of impulse responses from the tunnel reverb at the top of the show to the cathedral reverb for the court scenes and muting or un-muting microphones. The QLab session, media files, and Max patch are all bundled for the next performance of *The Right of Way*.

Conclusions

The Right of Way was the first major theatrical performance for which I designed all the sound. The opportunity, along with my graduate studies, provided further competence in integrating spatial sound in the theater setting. Graduate readings confirmed aesthetic choices in the live actor genre and informed the spatial sound arena. As with my work for Auragami, my experience with writer Thomas Murray assured my capacity for a fuller realization of the artist's concept through spatial sound design. The three full performances in the Cube demonstrated that using immersive multimedia was an enhancement to the script. Joe Salvatore, Clinical Associate Professor of Educational Theatre at New York University, provided an external review of the play. In his report, Salvatore notes:

[28] "Figure 53 | QLab." https://figure53.com/qlab/. Accessed 5 May. 2019.

"A sophisticated sound design utilizing the 140 speakers available in The Cube helped to establish the world of the play and the performance. I was particularly taken with the ambient sound of a bicycle moving around the theatre as the audience found their seats and waited for the performance to begin."

The Right of Way was a featured performance at the 2019 ACCelerate Festival at the National Museum of American History in Washington, D.C. The festival is a celebration of creative exploration and research happening at the nexus of science, engineering, arts and design.

rabies

rabies was born out of one question: what would a 1000 tom-tom drum solo sound like? I explored how to do this as part of an electrometal composition, partially inspired by a scare with a potential rabies virus exposure.

Design Choices

My sonic palette was inspired by bands Animals as Leaders[29], Mike Patton + The Dillinger Escape Plan, and the video game Splatterhouse 3[30]. These sources feature intense, complex music and sounds. Animals as Leaders integrates arpeggiated synthesizers as a layer underneath virtuosic guitar and drum performances. The collaborative album *Irony Is A Dead Scene*[31] by The Dillinger Escape Plan, featuring Mike Patton, is an explosion of complex metal, overdriven to the extreme. Splatterhouse 3, created for the Sega Genesis game console, is a horror house fighting game. Monsters with a rabid disposition are fought at every step. The sounds of their biting, dripping, and clawing assault the player in convincing sound design.

rabies opens with sounds of mucky, arpeggiated synthesizers. Frequency modulation synthesis and delays articulate a slimy environment, with cruel creatures bellowing over top of the synthesis, their voices harsh and discordant. To convey the primeval fear of rabies, and as release of my own fears, I performed several layers of vocals inspired by Tibetan throat singing. I processed these vocals with bit crushing, distortion, and automation envelopes to become strained and inhumanly guttural.

At 150 bpm, *rabies* moves quickly, especially when the drums and guitars enter, blasting syncopated sixteenth notes. Eight different layers of distorted guitars blend together, four per half of the room, with mechanical precision. Guitar samples and synthesizer triads are processed with a variety of distortion effects for punishing immersion.

The heaviest pummeling from all the drums culminates about halfway into the piece, with the triggering of individual tom-toms approaching the equivalent of 1/512 notes, and spatialized. Sixteen individual tom-toms, two kick drum tracks, two snares, quadraphonic cymbals, assault listeners like a spreading virus.

Sound design enhances the cruelty with bone saws and splattering blood. Occasional dog growls reinforce the guttural processed vocals.

The end of *rabies* culminates in the same cruel manifestation of rabies symptoms, as nerves fire with increasing speed and tension. The growls of creatures are now overwhelming and coming from all directions. The reprisal of cacophonic drums, the

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[29] "Animals As Leaders- Sumerian Records." http://sumerianrecords.com/artist/details/id:36/Animals+As+Leaders. Accessed 5 May. 2019.
[30] "Splatterhouse 3 - Wikipedia." https://en.wikipedia.org/wiki/Splatterhouse_3. Accessed 5 May. 2019.
[31] "Irony Is A Dead Scene | Discogs." https://www.discogs.com/The-Dillinger-Escape-Plan-With-Mike-Patton-Irony-Is-A-Dead-Scene/master/2621. Accessed 5 May. 2019.

increasing dissonance from the synthesizers, high frequency synths circling overhead, and discordant guitars overloading a listener to expiry.

Technical Implementation

rabies was composed in Reaper with MIDI and digital sound manipulation. The instruments used were created with synthesizers or sampled from real instruments.

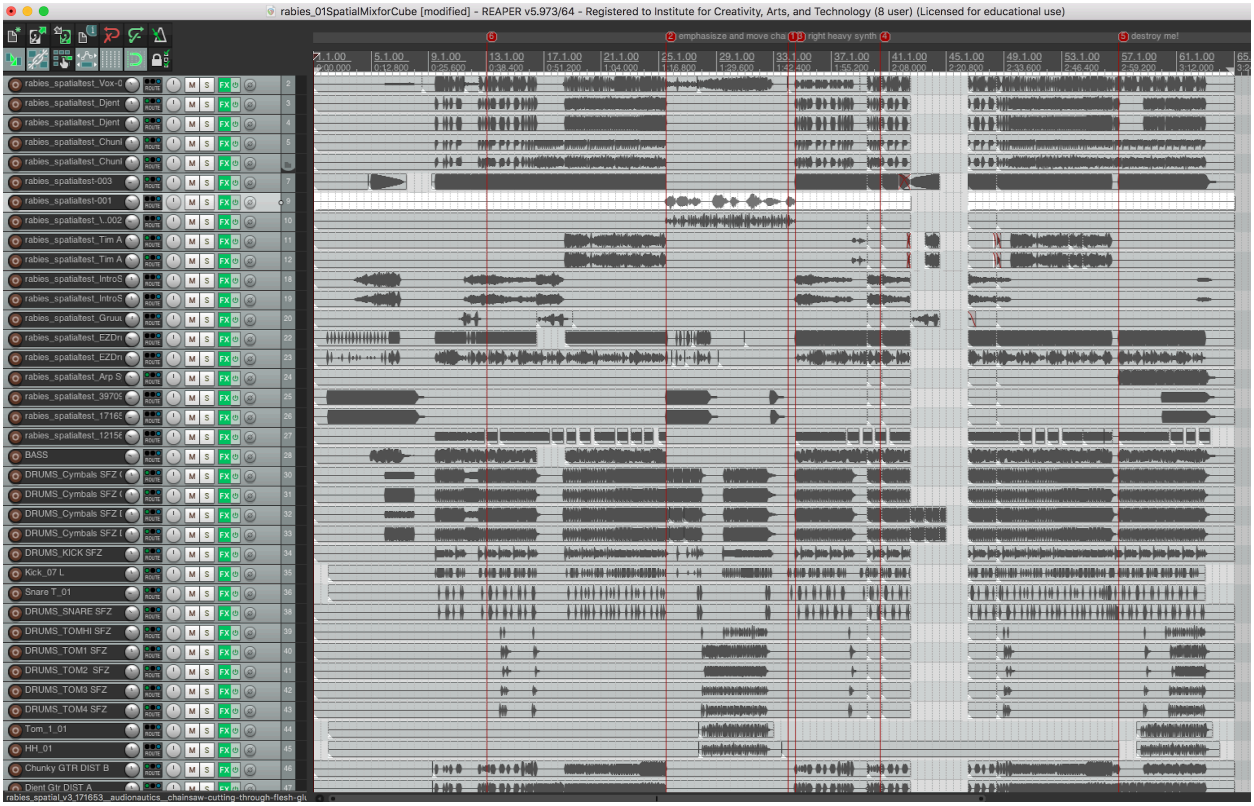

Figure 10 - Reaper multitrack mixing, *rabies*, Tanner Upthegrove

The MIDI drums were programmed with General MIDI sounds, and performed or sampled by Ryan Baker, a Massachusetts based composer and sound artist whom I have collaborated with since 2005. Baker has been an inspiration as a composer. Many processed guitar tracks were also processed or mixed by Baker.

After a stereo mix was created in Reaper, individual tracks were spatialized with the pipeline. This allowed total timbral control in Reaper where I could continue to process sounds with effects and busses during the spatial mixing stage. Encoding and decoding in Max made it possible to rapidly change mixing studios.

Conclusions

This piece was significant for me as an artist because I was able to use the pipeline developed for previous pieces to more efficiently arrange the spatial soundscape, especially with designed sound having individualized trajectories per track.

Spatializing instruments with sharp transients, like tom-tom drums, captured my intent for the piece, enabling a unique experience for the audience similar to what the percussionist perceives at a drum set.

Distributing the distorted guitars around the room was engulfing but resulted in a loss of acoustic resolution. Spatially grouping the guitars together would provide a more layered, localized sound.

rabies was performed at the December 12th, 2017 DISIS Concert, ICMC 2018, the 2018 Audio Engineering Society International Conference on Spatial Reproduction – Aesthetics and Science, and October 2018 at EnvelopSF.

Moogfest 2018

Under the guidance of Dr. Charles Nichols, Ryan McHugh and I created a design and performance studio for the Spring 2018 semester named Moogfest Studio. Moogfest Studio applies artist engagement, development, and marketing assistance to artists creating a spatial music performance for Moogfest[32]. Moogfest is a four-day music, culture, and technology festival held in Durham, North Carolina, based around Moog, a company dedicated to innovation in musical synthesizer design and manufacture, With assistance from ICAT, McHugh and I partnered with Moogfest to solicit artists performing at Moogfest 2018 to come to Virginia Tech and create a spatial audio performance, created in the Cube, to be performed at Moogfest.

During the semester, two performing artists worked with me in the Cube to prepare spatial audio sets for Moogfest. One artist could not attend, and we worked remotely.

Design Choices

Author & Punisher[33] visited February 3 and 4 for an intensive, two-day residency. Author & Punisher's aggressive style of Doom Metal is made real by a man who has become part machine by inventing mechanical musical instruments. Tristan Shone, who holds degrees in both mechanical engineering and fine art, is the sole band member. Shone has created his own controllers to serve as musical instruments for both performative and expressive elements. These controllers generate data to control outboard synthesizers or software controllers in Ableton Live. The performances are visceral and brutal as Shone uses a driving punch movements to trigger high-impact drum sounds with the Gridiron, a 3-D printed joystick with embedded buttons on a multi-track sensor. Another controller is named Minirack after the rack[34], a medieval torture device with rollers on both ends. Shone also milled large knobs, which when spun, continued for many seconds due to their mass. Shone created masks with more sensors

[32] "Moogfest." https://www.moogfest.com/. Accessed 5 May. 2019.
[33] "Author & Punisher (Official Page of works by Tristan Shone)." http://www.tristanshone.com/. Accessed 5 May. 2019.
[34] "Rack (torture) - Wikipedia." https://en.wikipedia.org/wiki/Rack_(torture). Accessed 5 May. 2019.

and microphones to process his vocals and add visual drama to his performance. With all of the sensors and stage presence, Shone appears captured inside a machine.

Figure 11 - Author & Punisher in the Cube, Photo Courtesy Dylan Parker

Individual audio channels and control data from the outboard synthesizers and controllers were available. Shone already created a data pathway for his video designer. I asked for a copy of the data and took the audio feeds into Max. From there, I created triggers to respond to incoming MIDI data from Shone's computer. As I was not familiar with all of pieces, I created a few spatial effects that I could choose and manipulate live.

For drum sounds, I made three modes. The first mode was a default omnidirectional position, so the kick and snare drums would come from all the loudspeakers. I chose this as both an engulfing posture for the kick drum, but also a safe spatial mix as there would be no place in the audience that missed the drums. The second mode was a trigger from the Gridiron. When the kick drum was triggered, the kick and snare drums would start at a small point overhead and spread out downwards, so the motion sounded like it was falling from above and engulfing in all directions. The third mode used the snare to randomly move cymbal and snare drum sounds around a central point. This mode was interesting in moment with more rapid, continuous percussion as it creates an effect similar to fireworks, where single streams light up and then fade over time.

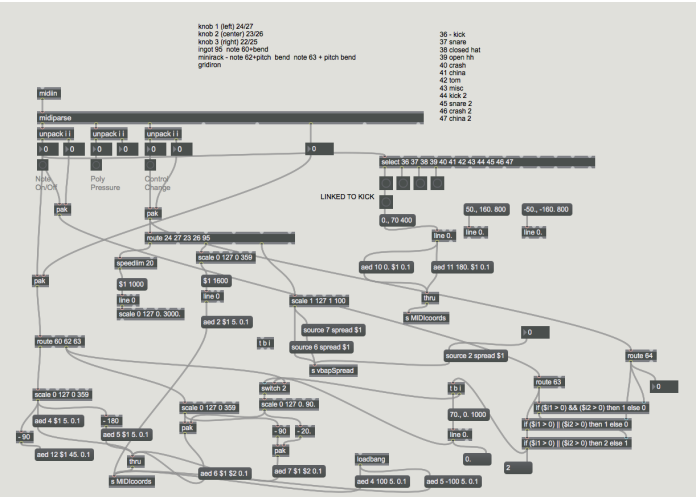

Figure 12 - Max code routing control data, Tanner Upthegrove

Synthesizer sounds had similar modes. Shone had primary and secondary synthesizer pairs, in addition to computer generated audio or samples. The default mode was static mix busses so that the primary stereo pair was at the front of house, and the secondary

synthesizer was bussed to the sides. The next mode took MIDI triggers from the kick drum and moved the busses. The front of house buss would swell in size with the VBAP spread function. The second side-fill buss would also swell and move from side-position to the back position. This automatic effect created an extra layer of dynamic control. The higher the MIDI velocity, the wider the spread and greater the movement. The third mode was open control for Shone. Shone would play the Minirack or a knob, which sent out MIDI continuous controller data. For one interlude in between pieces, Shone would use the knobs to control a sample. The first knob controlled the pitch and some processing, the second knob controlled amplitude, and the third knob controlled where the sound was located in a 360 circle around the audience.

Figure 13 - Author & Punisher in the Cube, Photo Courtesy Dylan Parker

I planned to operate spatial audio live for the Moogfest performance, so I built in some controllers to change the location and spread of individual sources. I used a Korg nanoKONTROL MIDI controller to manually operate and control channels and amplitudes alongside the front of Rob Mele, house mix engineer representing Meyer Sound.

Later in February, **Valgeir Sigurðsson**[35] visited the Cube for a three-day residency, culminating in a complete performance as an open-door rehearsal. Valgeir brought along his engineer Francesco Fabris. We were able to communicate with MIDI data already programmed into the set, a full performance titled *Dissonance*. Cues for lighting and video were streamed from Valgeir's computer to Francesco's control station, where I took copies and used MIDI control data. In addition to existing cues, we chose several key moments in Sigurðsson's composition to trigger new spatial cues by routing time code into the Max patch. One example is a plane fly-by sound, which flies overhead, from front of the venue to the back.

Figure 14 - Valgeir Sigurðsson in the Cube, Photo Courtesy Dylan Parker

A viola da gamba player was not present for the residency, so I built in a pathway for EQ and reverb for Fabris to control at Moogfest.

I broke out Sigurðsson's stereo mix into 18 analog busses. Sigurðsson then routed individual tracks from his Ableton Live session to the busses. As Sigurðsson and Fabris had the expertise and vision to unfold the stereo mix to the surround busses, my role was to facilitate the execution of the vision.

Fabris requested control over banks of loudspeakers with faders, so custom routes were made so that Francesco could vary amplitude for each wall, adding another layer of spatial control.

As *Dissonance* was a comprehensive audiovisual performance with a complete technical rider, much of the time in residency was dedicated to making all the elements work together. Projectors and moving lights were included and controlled by the

[35] "Valgeir Sigurðsson | Official Website." https://valgeir.net/. Accessed 5 May. 2019.

programming Fabris and Sigurðsson already planned. This residency also concluded with an open-door rehearsal, which was a full run of *Dissonance*.

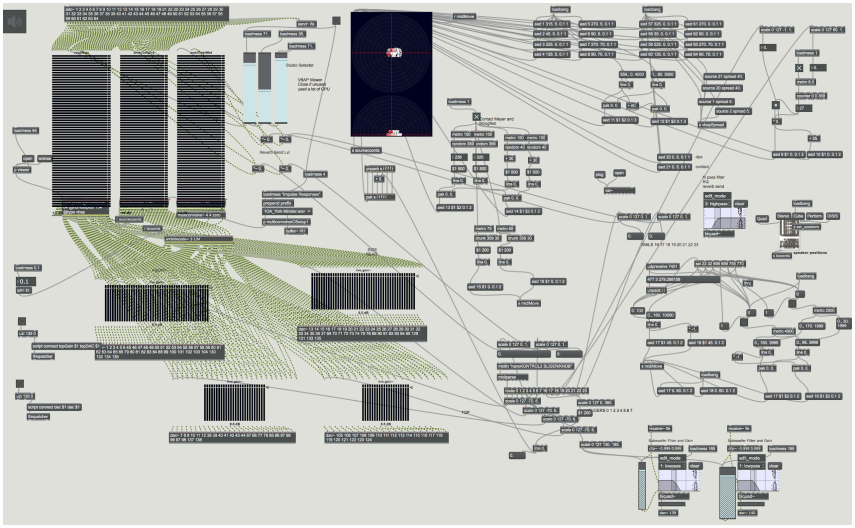

Figure 15 - Max code routing control data, Tanner Upthegrove

Finally, **Mouse on Mars** could not attend a residency at Virginia Tech, but were confirmed for Moogfest. Band members Jan st. Werner and Andi Toma already created a spatial music album using the d&b audiotechnik Soundscape platform, which they intended to play at Moogfest underneath live musicians.

As the Soundscape rendering hardware was not available for Moogfest, Toma and I communicated early on, exchanging files and examples to see if we could use the existing control data with my spatialization pipeline. I listened to the control data from the plug-in in a Logic X session by opening a UDP port in Max and reading the Open Sound Control (OSC) data coming in. From there, I sorted objects by unique identification numbers and mapped Cartesian coordinates of each object, which seamlessly integrated into the Max spatial audio decoder.

Technical Implementation

Moogfest designated the Armory[36], a city-owned venue originally built for Durham's National Guard Unit between 1935-1937, as the premiere spatial audio venue for the festival. The main stage has an audience capacity of 585 and the balcony adds another 314. The Armory itself does not have a spatial audio system, so Meyer Sound[37], official sound sponsor of Moogfest, stepped in to make the venue a reality.

I worked with Meyer Sound's Steve Ellison, Richard Bugg, Alex Harbaugh, and Rob Mele on designing and implementing a spatial audio system. Planning began in October 2017 to determine how to best represent the variety of artists in the venue. Despite nearly all parties desiring an in-the-round staging circumstance where audience surround the performers, we landed on thrust staging, a stage that protrudes into the audience area,

[36] "Durham Armory - History Beneath Our Feet." http://museumofdurhamhistory.org/beneathourfeet/landmarks/Armory. Accessed 5 May. 2019.
[37] "Meyer Sound." https://meyersound.com/. Accessed 5 May. 2019.

as the technical complexity and schedule demanded it. As some of the artists in the Armory would not be using prepared, spatialized audio, we agreed that a traditional front-of-house system should accompany the spatial audio system. We agreed to put the densest concentration of surround loudspeakers around the audience as close to head height, as well as an overhead channel on a truss totem. The design drew from the Moogfest 2017 25.4 channel system that I co-designed with Dr. Mike Roan, Professor of Mechanical Engineering at Virginia Tech.

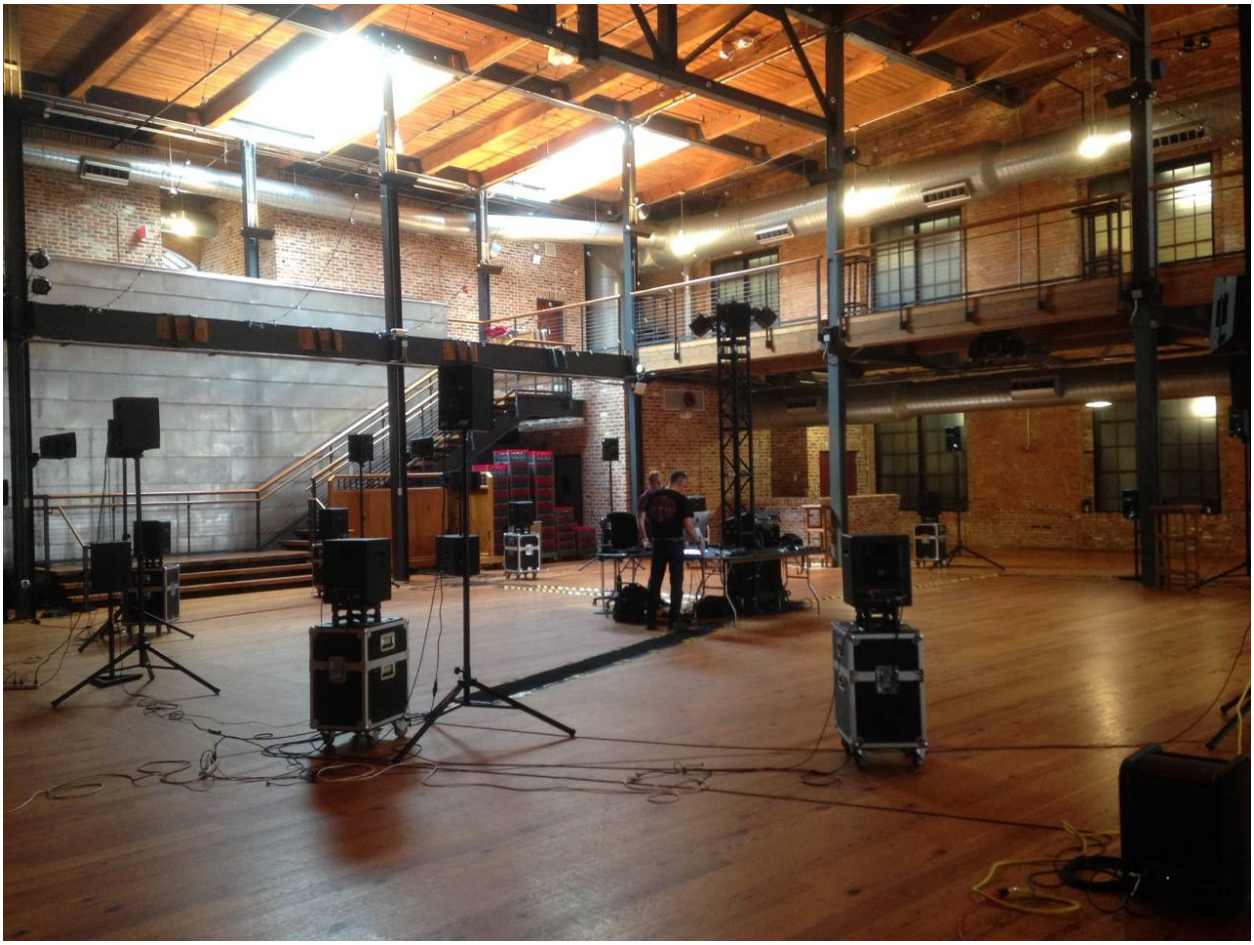

Figure 16 - Moogfest 2017 Bay 7, 25.4 HDLA, photo courtesy Charles Nichols

The final design was a pair of Meyer LEOPARD line arrays for left and right front of house loudspeakers, 18 Meyer UPJ loudspeakers equally distributed around the listening area, four Meyer UPJs on the overhead totem truss, four Meyer LFC 1100 subwoofers in quad, two VLFC ultra low subwoofers at the stage, and a quadraphonic monitoring system on stage for performers to get a submix of the house spatial mix. In total, 51 loudspeakers were used. Meyer Sound provided D-Mitri powered signal processing and matrix control, with SpaceMap[38] for 3-D panning. Analog inputs from the stage went to D-Mitri for mixing and signal processing.

[38] "SpaceMap - Lighting & Sound America." http://www.lightingandsoundamerica.com/reprint/meyerspacemap.pdf. Accessed 5 May. 2019.

All of my code was hosted on a Mac Pro, which had 24 channels of bidirectional input and output to D-Mitri by a MOTU USB soundcard with AES3 inputs and outputs. I also ran ethernet to the stage for artists sending me digital audio and control data over a network.

SpaceMap and my pipeline could run at the same time. At times, I left the convolution reverb available as a send for Rob Mele to add to mixes.

Conclusions

Author & Punisher's set was the first and started off with a technical problem. The VBAP spread was not fully activated, causing the sounds to seem small and not diffuse enough across the entire system. By the end of the first song, this was resolved, and I was manually controlling spatial movements along with automated movements. The performance was so loud that many of the movements heard in the Cube were not present. Stylistically, this was not a problem for the audience as the visceral loudness was enjoyable and being surrounded by sound gave the impression of weight, a physical presence. The 360-knob movement worked well and was a nice palate cleanser when used between pieces.

Dissonance by Valgeir Sigurðsson executed accurately with an intense technical setup run right before the show. The lighting and projection cues complemented the performances of Sigurðsson and Liam Byrne, viola da gamba. Ellison, who had a rare opportunity to enjoy a set during the chaos of the festival, stated the performance was close to a "religious experience." This performance was also acoustically engulfing and so loud that much of the subtlety planned in residency did not convey as it did in the Cube. However, the distributed busses offered changing perspectives if one walked around the venue during the performance.

The performance by Mouse on Mars was the most technically challenging, but also most rewarding, as Steve Ellison and I simultaneously live-spatialized the set with our different techniques. This concert was the final concert in the venue and combined all the efforts of Meyer Sound and Virginia Tech to support an artist. The venue was packed to capacity.

My experience at Moogfest was challenging and enlightening. As a designer, I learned two lessons. The first lesson was that if the HDLA is too loud, any subtlety in spatialization is lost. Some of the performances were so loud that localization of sounds was not possible. The second lesson was a confirmation of the discussion I had with Trey Spruance that planning and preparation are required to make a compelling spatial audio event. For some of the performances, we did not have enough time to prepare in residency, and the festival schedule was so tight that there was no room for error before the show. Meyer Sound did the heavy lifting of making sure every event ran smoothly. Most of these issues can be resolved with more time to plan and rehearse.

"**This year's Spatial Sound programming was the centerpiece of the festival** and as such, Virginia Tech's participation was heavily promoted on all social channels and press outreach, and each performance and conversation was live streamed in full via YouTube, Facebook, and UphoricTV. **The Spatial Sound livestream is estimated to have reached over 10 million viewers** from each source combined." - Parag Bandari, Moogfest 2018 CEO

Poe's Shadows

Following the success of the immersive theatrical installation *Shakespeare's Garden*[39], the team regrouped to design an immersive theatrical installation based on the texts of Edgar Allan Poe. Choosing selections from The Raven and The Tell-Tale Heart, Amanda Nelson, Natasha Staley, Meaghan Dee and I opted to use the Cube as our venue. We wanted to use the Cyclorama for a scrolling visual experience, which was inspired by crankies[40]. Crankies are hand-turned, visual narratives on scrolls with painted scenes and shadow puppets. The Cyclorama is a 360 degree, sixteen-foot-tall immersive projection system. We also wanted to use the spatial audio system in the Cube to complement the immersive visual experience.

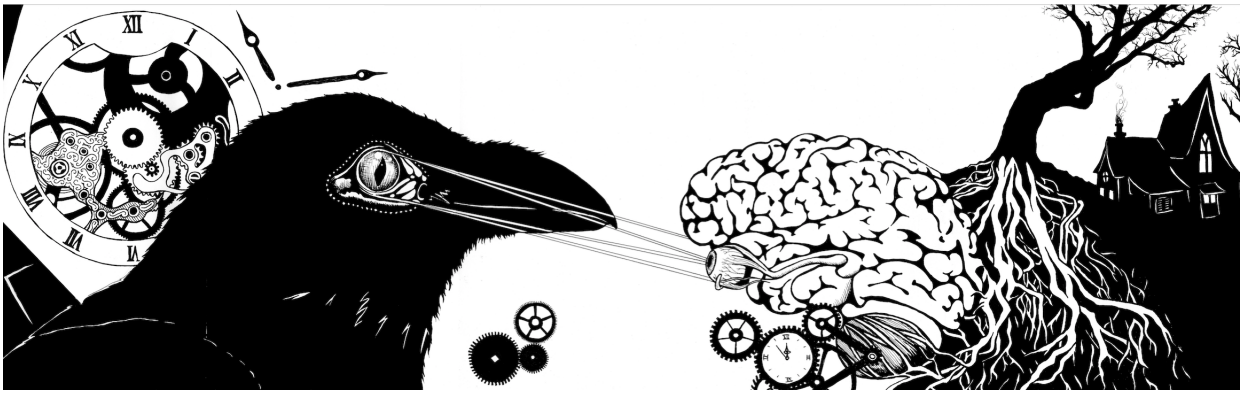

Figure 17 - Original artwork by Meaghan Dee, *Poe's Shadows*

Cast
The Tell-Tale Heart performed by Austin Burch
The Raven performed by Reiss Gidner, Erika Koekkoek, and Liv Wisnewski

Creative Team
Visuals and Graphic Design: Meaghan Dee
Sound Design, Composition and Technical Direction: Tanner Upthegrove
Text Curation: Amanda Nelson, Natasha Staley, and Ashley Reed
Performance Directors: Amanda Nelson and Natasha Staley
Lighting Design: Gustavo Araoz
Virtual Reality Component Design: Dillon Cutaiar, Chris Miller, and Todd Ogle
Project Manager: Liz Kurtzman

Design Choices

Inspired by Poe's texts themselves, crankies, a 19th-century technology for storytelling, and shadow play or puppetry, the installation explored the concept of shadow through text, image, and sound.

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[39] "'Shakespeare's Garden,' an immersive theatrical ... - Virginia Tech Daily." 14 Mar. 2018, https://vtnews.vt.edu/articles/2018/03/sopa-shakespeares-garden.html. Accessed 5 May. 2019.
[40] "HISTORY SECTION - www.thecrankiefactory.com." http://www.thecrankiefactory.com/115034629. Accessed 5 May. 2019.

As a team, we chose to run *Poe's Shadows* as a fixed-media, fifteen-minute loop. The reasoning was mostly pragmatic as we chose to have only 30 seats available for *The Tell-Tale Heart* inside the Cyclorama. The team chose to bookend *The Tell-Tale Heart* with *The Raven* by featuring one half of *The Raven* before *The Tell-Tale Heart,* and the second following the completion of *The Tell-Tale Heart*.

Audience entered to ambient sounds of *The Raven's* narrator's residence and were encouraged to walk around the Cube, lit by dynamic theatrical lighting. For this scene, the lighting was on the outside of the Cyclorama with tree gobos, sleeves inserted into lighting instruments to cast a specific shadow. The lighting slowly pulsed, with different fixtures out of phase with each other, encouraging audience to explore the perimeter of the Cube while spatial sound moved around them. I created a fireplace sound in the opposite corner of entry to draw audience in. Cold wind sounds made the room feel expansive. Occasionally, the voices of narrators Erika Koekkoek, Liv Wisnewski, and Reiss Gidner tempted audience deeper in to the Cube. When the reading of *The Raven* began, their voices hovered and moved the haunting words of Poe through the Cube, floating like spirits recounting the tale. To add a touch of otherworldliness, I processed the voice recordings with a small amount of granular synthesis and delay to create ethereal aural trails, following the clean recorded voices. The rapping at the chamber door is jarring. Then, as summoned by the narrator, a raven descends from above and perches inside the room. The husky squawks of a real raven recording sounds large and imposing. With the dim, pulsating lighting, *The Raven* felt both eerie and omnipresent.

The ambient sounds continued as the actors from *The Raven* ushered audience into the center of the room with spoken spatial cues, suggesting, "this way…" and, "in here!" Additionally, red, pulsing light increased inside the Cyclorama to indicate urgency to occupy the Cyclorama. The house goes completely dark and silent.

Austin Birch's narration of *The Tell-Tale Heart* breaks the silence and darkness. The voice comes from all directions, creating the feeling of being inside the narrator's head:

"True! --nervous --very, very dreadfully nervous I had been and am; but why will you say that I am mad? The disease had sharpened my senses --not dulled them. How, then, am I mad? Hearken! and observe how calmly I can tell you the whole story." -Edgar Allan Poe

Birch's fervent performance captured the intense paranoia of the narrator character.

I composed music and sound design to follow the narrator's descent to murder, emphasizing the theme of shadow when possible. The composition *Poe's Shadows* begins at the same time as Dee's animation as the narrator utters, "the whole story." I used aggressive jeté-bowed string ensemble samples, arpeggiated in contrast to a wandering, slurred flute. The flute represents the narrator's wandering mind while recounting the events of the story. Harpsichord accents establish a mid 19th century spooky context in tandem with the visual elements scrolling by. I drew inspiration from

Le Mani Destre Recise Degli Ultimi Uomini[41], a Secret Chiefs 3 concept album pulling from Giallo film[42] score influences. Giallo films come into existence over 100 years after the first publication of *The Tell-Tale Heart* in 1843 *yet* parallels of suspense and horror are consistent. The delay effects used in pieces like *Faith's Broken Mirror* embody an aural shadow. I mimicked this style, while panning the delays around the room with the image. This effect alerts an audience that sound can come from any direction at any time. I chose to emphasize this vulnerability to enhance the experience of being with the mad narrator. The music does not return until the end, when the narrator's paranoia is the most intense. The same aggressive strings return, with spatialized delay, heightening the narrator's emotional state.

The sound design choices fell into two considerations. The first was implementing the major callouts in the story. These cues are realistic and designed to keep the audience in the world of the narrator by enhancing a description by the narrator or an action in the scene, by the narrator or from Dee's illustrations. I used spatialization to give the impression of being in the same room as the story. A cold wind blows. A distant bell tolls twelve times on the first night that the narrator visits the Old Man while sleeping. The creaking of the door and lantern coincide with similar visual elements. Snores emanate from another direction behind the room. Later in the piece, the narrator returns and violently throws open the door and charges the Old Man, killing him by pulling the heavy bed over him. The sounds of running footsteps on wood floors pan across the room, with a Wilhelm scream-like shriek, conclude with the cacophonous crash of a springy iron bed tumbling, cloth flapping, and body thuds. A final example of the realistic cues comes in the final thrust of the story when the police arrive. A jarring knock at the door comes from the opposite side of the room where the action was previously focused. The men enter and as they search the home, their footfalls surround audience. Furniture moves on wood floors, setting the last action cues where the narrator shifts the chair around in a panicked frustration.

The second sound design challenge was the representation of the distorted reality of the narrator. After the narrator's first visit at midnight, the narrator returns to the home of the Old Man for seven consecutive nights. I slowed the pitches and speed of repetition of the bells to indicate the passage of time. The changing pitches are unusual and represent a further descent from normal behavior. Another example distorted reality is the exaggerated composite of disgusting sounds during the grotesque dismemberment of the Old Man. I equidistantly spatialized spurting, sputtering, and splatter sounds around the room as the narrator nonchalantly describes the task. "If still you think me mad, you will think so no longer when I describe the wise precautions I took for the concealment of the body. I worked hastily, but in silence. I dismembered the corpse. I cut off the head and the arms and the legs." The sounds briefly overtake the narration with gory splattering during the word "dismembered," so the audience perspective is that of the narrator, showered in carnage. The most prominent example

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[41] "Le Mani Destre Recise Degli Ultimi Uomini - The Severed Right ..." https://www.discogs.com/Secret-Chiefs-3-Traditionalists-Le-Mani-Destre-Recise-Degli-Ultimi-Uomini-The-Severed-Right-Hands-Of/master/136067. Accessed 5 May. 2019.

[42] "Giallo (film) - Wikipedia." https://en.wikipedia.org/wiki/Giallo_(film). Accessed 5 May. 2019.

of the distorted reality comes from the text, which is the tell-tale heart itself. “--now, I say, there came to my ears a low, dull, quick sound, such as a watch makes when enveloped in cotton. I knew that sound well, too. It was the beating of the old man’s heart.” I used the sound of an antique pendulum clock and modified the timing so that beating resembled diastole and systole. I then duplicated this pattern to have a baseline heartbeat to work with. To fill out the sound more, I used the Cockos plug-ins ReaGate and ReaSamplOmatic5000 to generate a MIDI note based on the heartbeat transients. The sampler adds a bass note and the sounds mix together. I mixed these elements so that I could distort reality in the Cube, by increasing or decreasing the amount of bass depending on the intensity of the scene. During the murder, the heartbeat of the Old Man increased the narrator’s fury. I also increased the rate of heartbeat during this scene. At the climax when the police are investigating the home, I wanted to convey the oppression felt by the narrator. I consistently increased the rate of the heartbeat during this scene, as well as the level off bass. Because the frequency of the bass was so low, the subwoofers in the Cube made the heartbeat visceral.

Technical Implementation

Nelson, Staley, and I had three recording sessions where we captured performances of the voice actors. I used Sennheiser e614s on each performer individually, for both *The Raven* and *The Tell-Tale Heart.* I used a tube microphone built by Dr. Michael Roan to capture the ensemble for *The Raven*, and Birch for *The Tell-Tale Heart*. After several takes and evaluations with Amanda and Natasha, we agreed upon final performances, which I edited into one document.

In parallel, I was composing and designing sound to pair with the visual elements under guidance of Dr. Charles Nichols. I used Reaper to compose the score and MIDI controlled synthesizers and samplers for generating the sounds. I used the actor’s performances and Dee’s visuals to finalize the timings of cues.

I combined all sound into one Reaper file so that I could spatially control each sound with my spatialization pipeline. I also timed the entire show to play back in a perfect 15-minute loop. A separate Max patch on the same computer rendered the spatialized the sound and received MIDI time code from Reaper to trigger the lighting console cues with OSC. The Max patch also triggered Dee’s animation on the Cyclorama with OSC. Timecode also triggered different 3-D reverb settings.

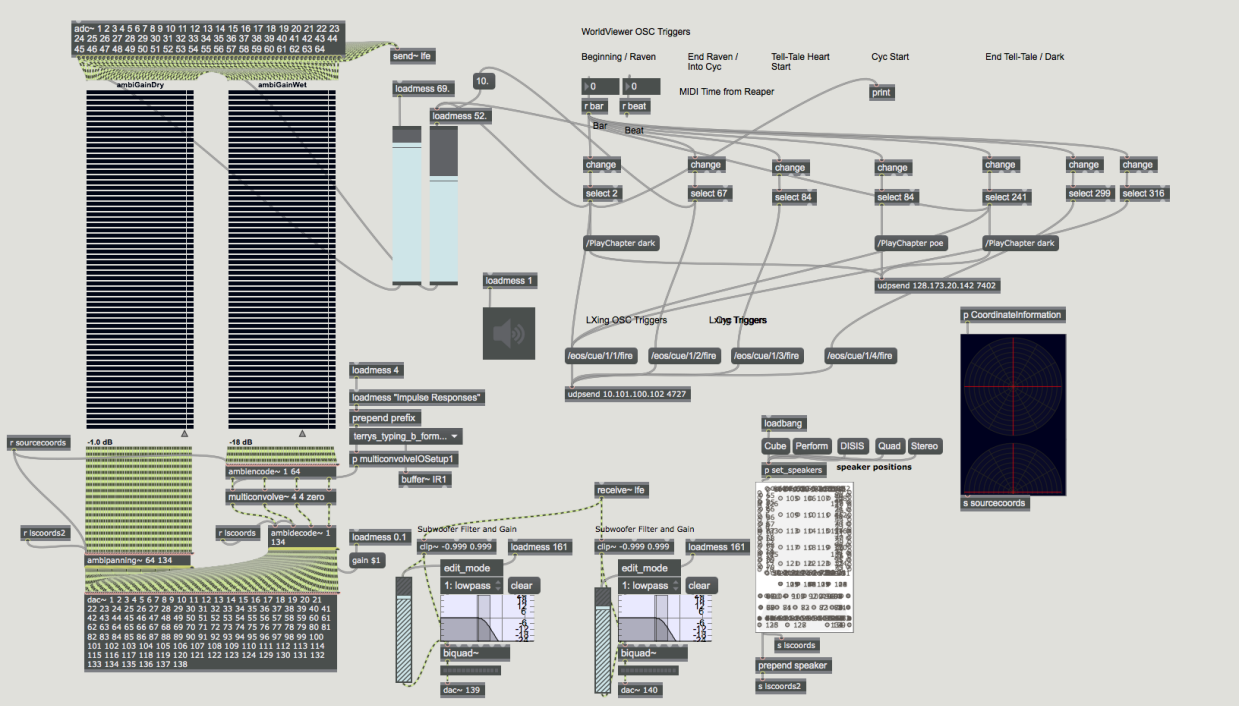

Figure 18 - Max patch controlling spatialization, lighting, and projection, *Poe's Shadows*, Tanner Upthegrove

Conclusions

The team brought to life stories that are nearly 200 years old in a way that is novel and engaging. The strength of the team enabled a project bigger than any of us could do on our own. *Poe's Shadows* is an exemplary work of immersive theatre in an installation format. I predict more immersive theatrical works like this will emerge.

Our team requested audience complete a survey after *Poe's Shadows.* The responses were helpful in building future presentations. Of the 345 responses, 95.33% of the audience who completed the survey indicated they could follow the story in *The Tell-*

Tale Heart.

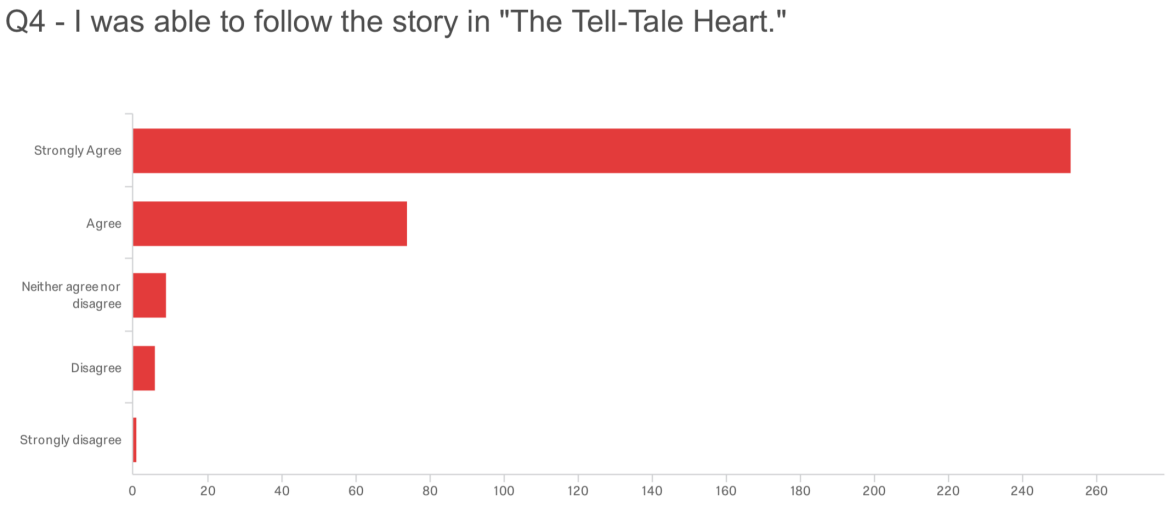

Figure 19 - Post event survey results, *Poe's Shadows*, Liz Kurtzman

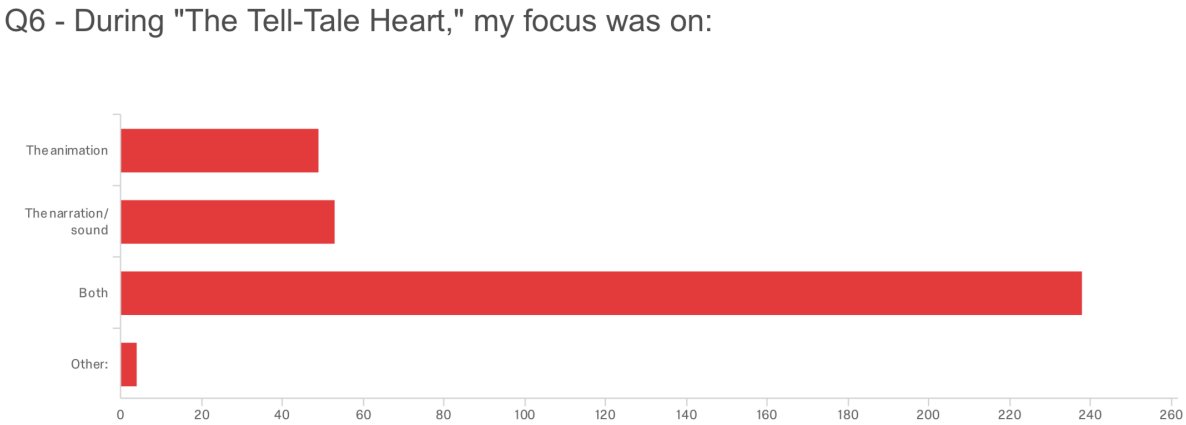

Figure 20 - Post event survey results, *Poe's Shadows*, Liz Kurtzman

A variety of emotions were experienced while moving through *Poe's Shadows.* Some comments from the "Other" field include on edge, interested, immersed, curious, intrigued, captivated, dizzy, surrounded, and engaged.

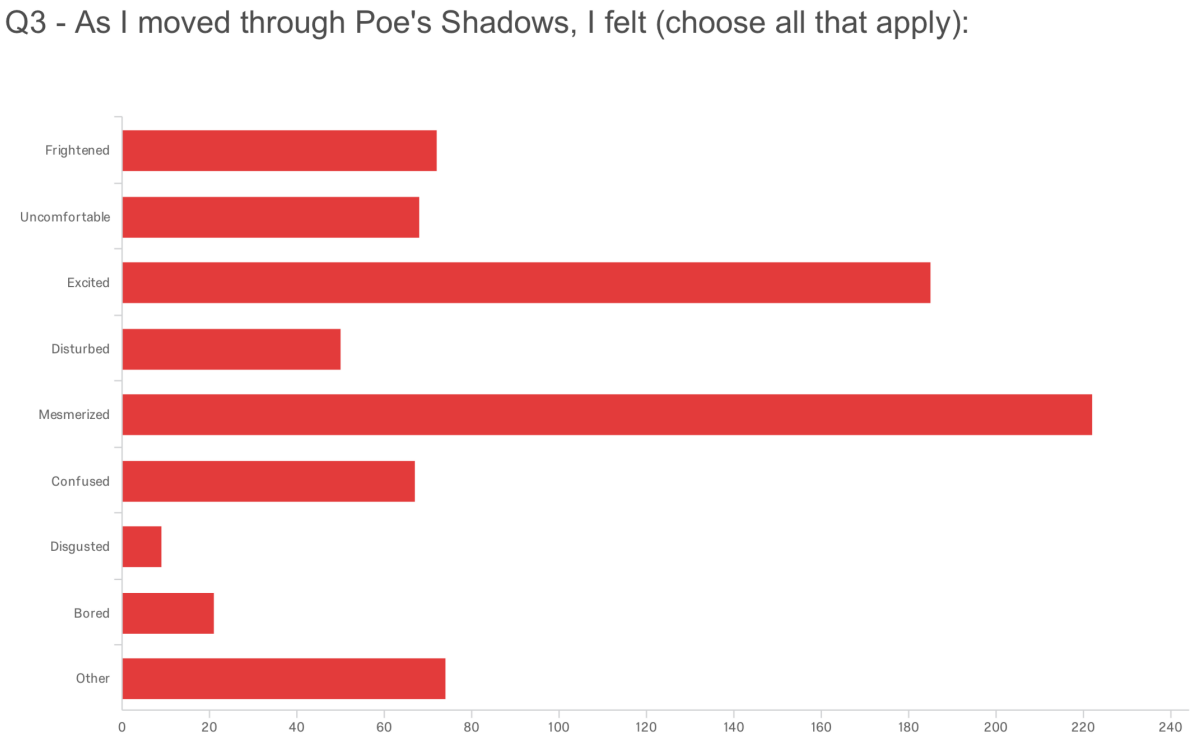

Figure 21 - Post event survey results, *Poe's Shadows*, Liz Kurtzman

Free form responses indicated there was confusion about the ambulatory experience in *The Raven*:

[sic] "The audio directions were somewhat confusing. It was unclear where we were suppose to go."

"During the Raven, my confusion about where to stand took away from the experience. VERY cool though"

On March 4th, 2019, *Poe's Shadows* was recognized by the Western Virginia Advertising Awards, American Advertising Federation:

Gold ADDY, Events – Poe's Shadows

Gold ADDY, Illustration (Series) – Poe's Shadows

Spatial Tapas

I composed several short pieces of music, inspired by Spanish tapas[43]. A tapa is a small appetizer or flight of small plates. The intent was to create several different flavors of music for spatial audio systems. I wanted to create short pieces so that I could explore several different styles in one semester.

Design Choices

Synthetic Six Arm God for the Unexplored World

Synthetic Six Arm God for the Unexplored World, or *Six Arm*, is directly inspired by the resurgence of synthwave aesthetics in popular media. After hearing hours of different kinds of synthesizers in use at Moogfest, I wanted to go more in-depth with hardware synthesizers. In particular, Suzanne Ciani spoke about her synthesizers for quadraphonic sound and described [paraphrasing] "synthesizer audio is inherently 2-D, and multichannel audio is the perfect complement." Dr. Nichols provided several examples of computer music that use synthesis for me to evaluate. John Chowning's *Sabelithe* stood out to me because of the panning and synthesizer sound choices.

I imagine the Six Arm as a fleet of large space vessels in a cold, automated future and this piece is their arrival. A staccato arpeggiation of blocky bass eighth notes in the 6/8-time signature opens the piece. The sound from each note is sent to a different channel of a six-channel buss, where each buss is equidistantly spaced around the listener. The arpeggio fades in, clouded by swells of synthesizer pads. Eighth note "huffs" emerge, which rotate and vary location around the listener like a force field. The blocky bass and huffs persist throughout the entire piece. The envelope changes so that the staccato notes become legato by the end of *Six Arm*. The timbre changes gradually too, becoming sharper and more resonant. Applied resonant filters sweep the huffs, as though the force field is responsive to the environment. A melody emerges between engulfing swells. I spatialized the melody overhead, like a tractor beam from the vessels above.

Bunga Bunga

Bunga Bunga is the soundtrack for overconfident, corpulent men who specialize in back-room agreements. After humming and singing to my one-year old daughter, I fixated on some rhythms that led to *Bunga Bunga*. I wanted to use Latin percussion and retro organs to create an aural environment that would manifest a trickster cavalcade. Or Silvio Berlusconi.

[43] "Tapas - Wikipedia." https://en.wikipedia.org/wiki/Tapas. Accessed 5 May. 2019.

I recorded myself making pops and clicks with my mouth to make percussion instrument samples. I started by arranging the vocal percussion samples into syncopated polyrhythms at a jaunty 105 bpm tempo. These varied rhythms sounded at home when spatially mixed and open the piece in rich, 3-D reverb as an invitation to events happening all around the listener. A farfisa organ, processed with band pass filtering, pops in with the melody and harmony like a cheap suit at a smoky party. I used tympani to manifest a large belly jutting and strutting, showing no regard for anything else in physical space.

Drum Buddy

Building upon a finding of *rabies,* that strong transients, such as the striking of a percussion instrument, take advantage of our natural ability to localize sound, Drum Buddy explores spatialized percussive styles with polyrhythm. The original version, composed with MIDI in Reaper with free Soundfont, shapes dense layers of percussive instruments into rapidly changing samplings. In the spirit of tapas, *Drum Buddy* moves from flavor to flavor, opening with a spicy initiation. The transition into the next course is marked by rapid, transient-rich, staccato hand drum rolls. High frequencies from triangles mixed with bongos and other hand drums in 14/4 time represent a sweet-savory combination, with polyrhythms fulfilling depth and balance. The complexity felt when the instruments are spatialized is interesting as individual instruments can all be localized, which may be an interesting technique for demonstrating and teaching polyrhythm. Next, an electric dance section inspired by Brazilian Carnival[44] establishes a familiar reference point in 4/4 before concluding with a crescendo of every instrument playing together.

I hope to have *Drum Buddy* performed by live musicians in an antiphonal configuration.

grindcoar

Building off *rabies*, this exploration into self-destructive noise and impossible black metal[45] are beginnings for incorporating computers into technical and progressive metal styles. I used instrumentation from black metal and djent[46] for the base recordings. Distorted guitars and drum sets are performed as blast beats, typically 1/6th or 1/32nd notes at a fast tempo. As an homage to surf guitarists such as Dick Dale[47] who inspired future metal guitar styles, a wash of spring reverb[48] was added to an ambient guitar track.

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[44] "Brazilian Carnival - Wikipedia." https://en.wikipedia.org/wiki/Brazilian_Carnival. Accessed 5 May. 2019.
[45] "Black metal - Wikipedia." https://en.wikipedia.org/wiki/Black_metal. Accessed 5 May. 2019.
[46] "Djent - Wikipedia." https://en.wikipedia.org/wiki/Djent. Accessed 5 May. 2019.
[47] "Dick Dale's Official World Wide Website." http://www.dickdale.com/. Accessed 5 May. 2019.
[48] "Spring Reverb 101 — Pro Audio Files." 9 Mar. 2018, https://theproaudiofiles.com/spring-reverb/. Accessed 5 May. 2019.

I made dozens of sub sections for djent ensemble, then ordered a few of them in a manner that seemed juxtapositional to each other to create a feeling of persistent evasion. Most of the parts are programmed with MIDI and are not possible for a human to perform. I added time-stretching and arbitrary editing to enhance the impossibility. I spatialized individual instruments and busses of instruments to create layers on layers, as inspired by Phil Spector's Walls of Sound[49]. I intended to make each of the five walls of the Cube a wall of sound, activated by different parts of the composition. The transients trigger rapid changing between walls for an effect similar to *rabies,* but a coarser brush instead of the fine punctuation of a few thousand tom-toms.

Conclusions

The spatialization pipeline I created, and the cumulative experience of previous works have made it clear that spatial audio can realize music that I hear in my mind. The four pieces I made as part of the Spatial Tapas series are brief, averaging two minutes each, but once composed, were easy and enjoyable to create.

[49] "Wall of Sound - Wikipedia." https://en.wikipedia.org/wiki/Wall_of_Sound. Accessed 5 May. 2019.

Conclusion

Through four years of creative practice and technical implementation, I have developed as a composer, sound designer, and technician for high-density loudspeaker arrays. As a composer, I gained experience working with crowd-sourced media in *The Galileo Project*. Innovation flourished in collaborative projects like *Auragami*, with Trey Spruance, and *Poe's Shadows* with visual artist Meghan Dee, widening the scope of creative possibility.

Recognizing my own limitations from my first efforts with *The Galileo Project*, I set out to master the hardware design and software concepts necessary to realize artistic intention with high-density loudspeaker arrays. The importance of high order ambisonics became apparent with my composition of *The Jury*, and I embarked on an exploration of the challenge which led me to an efficient, reliable, and novel pipeline to connect multichannel audio mixing and real-time HDLA sound spatialization. In co-designing an HDLA with Meyer Sound for Moogfest 2018, I benefited from fast-prototyping, which instructed my understanding of hardware and space limitations, especially concerning sound pressure levels, a topic for further exploration in the HDLA setting.

In my role as designer, such as for Moogfest 2018, *Right of Way*, and in all of the mentioned projects, I found that despite the occasional complication, the artist's intent was more fully realized with the addition of spatialization enabled by the HDLA and my own coding and live-manipulations. This realization was most fully in effect when I implemented my knowledge of high order ambisonics, and the coding that supports it, to bring my latest Tapas of compositions to fruition. My studies and experiences in spatial sound over the last four years have enabled the artist's greatest tool for expression--control.

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Appendix

The Galileo Project

https://soundcloud.com/tanneruptheGrove/the-galileo-project

The Jury

https://soundcloud.com/tanneruptheGrove/the-jury

rabies

https://soundcloud.com/tanneruptheGrove/rabies

Synthetic Six Arm God for the Unexplored World

https://soundcloud.com/tanneruptheGrove/synthetic-six-arm-god-for-the-unexplored-world-stereo

Bunga Bunga

https://soundcloud.com/tanneruptheGrove/bunga-bunga