SONIFYD: A GRAPHICAL APPROACH FOR SOUND SYNTHESIS AND SYNESTHETIC VISUAL EXPRESSION

Woohun Joo

Virginia Polytechnic Institute and State University,
Human Centered Design,
Blacksburg, VA, USA
joowh@vt.edu

ABSTRACT

This paper describes *Sonifyd*, a sonification driven multimedia and audiovisual environment based on color-sound conversion for real-time manipulation. *Sonifyd* scans graphics horizontally or vertically from a scan line, generates sound and determines timbre according to its own additive synthesis based color-to-sound mapping. Color and sound relationships are fixed as default, but they can be organic for more tonal flexibility. Within this ecosystem, flexible timbre changes will be discovered by *Sonifyd*. The scan line is invisible, but *Sonifyd* provides another display that represents the scanning process in the form of dynamic imagery representation. The primary goal of this project is to be a functioning tool for a new kind of visual music, graphic sonification research and to further provide a synesthetic metaphor for audiences/users in the context of an art installation and audiovisual performance. The later section is a discussion about limitations that I have encountered: using an additive synthesis and frequency modulation technique with the line scanning method. In addition, it discusses potential possibilities for the future direction of development in relation to graphic expression and sound design context.

1. INTRODUCTION

This project starts from an idea of what sound graphic design makes. In 2014, I completed my master thesis project titled “Transition between Color and Sound” at Rhode Island School of Design. This became a starting point of my color-sound study. My thesis project demonstrated how graphics can be transferred into sound, however, in terms of sound design aspect, I founded some issues. The lightness to amplitude mapping for an additive synthesis design was not very noticeable. For example, if timbre is determined by 1000 pixels and lightness of each pixel is mapped into an amplitude of each partial, it is not easy to recognize the differences over amplitude changes.

I have been exploring a synesthetic design approach [1] based on a color-sound conversion in order to go beyond the previous issues I mentioned and designing a functioning platform that possibly can be fully utilized as a tool for multimedia, audiovisual and musical expression with an immersive real-time projection of the image scanning process.

The ultimate goal of this research is to stretch traditional approaches of visual design/music, and to extend our understanding of multi-sensory experience design to cultivate visual and musical aesthetics.

For better understanding of how this system can be presented, my installation work, *Demo1 installation*, is attached. I have enhanced its functionality by applying a control interface, code based graphic presentation (instead of using a still image file extension such as JPEG) and more complex color-sound mappings coming with an amp modulation and FM-based sub-oscillator.

Sonifyd consists of three components: the first canvas that displays graphics/images, the second canvas that shows an image scanning visualizer meaning the image scanning processes, and lastly the sonification engine. Processing [1] codes are given on the basis of *Sonifyd*’s graphic component and the graphics will feed into MaxMSP[2] to create sound. Both components are controlled via an OSC [2]-based control interface, such as changing colors and the position of the shapes.

The creation of the codes written in Processing and variable changes via the OSC controller given motivates the user to explore a unique and spontaneous sound creating environment. During this procedure, the original graphic sources transferred to MaxMSP produce a dynamic visual feedback reflecting the image scanning process. This visual feedback provides more intuitive sound making experience and allows instant monitoring between graphics and sonic character; this scanning process will be further discussed in Section 3.

I applied a line scanning method that captures data in line with an invisible scan line. This is a visceral way to interpret 2D graphics because this scanning method can be understood in a similar way to a regular DAWs' approach; for example, Ableton Live's clip view has a scan line moving left to right to read MIDI data or audio contents.

In terms of the mapping between colors and sounds, it is firstly fixed within a particular range (in an octave). However, the range of the color-sound mapping can be extended or shortened according to a user’s preference. This flexible nature of the system may seem chaotic at first, but users will acquaint themselves with repetitive uses like the way we memorize words from other languages. The mapping between color and sound will be described in Section 3.3.

[1] https://processing.org/

[2] https://cycling74.com/

2. BACKGROUND AND RELATED WORK

The conversion of graphic into sound, or also known as graphic sound synthesis [3], with a concept of synesthetic design culminated in my master thesis in 2014. Since then I have been developing this sonification inspired multi-sensory design approach from there. The works by famous audiovisual artists such as Ryoji Ikeda, Carsten Nicolai, Olaf Bender and Brian Eno, although their works are intended to be sound/media art rather than sonification, have turned into my artistic inspiration and motive power for my ongoing color-sound research. I further saw the potential of this multi-sensory design approach as an assistive device with Neil Harbisson's Eyeborg[1]. There was another noticeable auditory display scenario working as an assistive tool. Khan et al. [4] developed an exercise platform for visually impaired individuals.

The multi-modal character of synesthetic phenomena has attracted much of academic attention, creating various types of an art form embracing visual and sound in fine art, multimedia and sound field. These approaches have a long history that is outside the range of this paper. However, it is relevant to briefly review precedent works where sound character is applicable graphically. There must be a close connection with early analog sound-on-film techniques and glass disc type instrument, starting from Piano Optophonique[2] and a Russian composer Arseny Avraamov's the first hand-drawn, animated, and ornamental soundtrack. An engineer Evgeny Sholpo developed a photosynthesizer called Variofon [5] with Rimsky-Korsakov's support as well. Under the Multzvuk group in the Soviet Russia, founded by Arseny Avraamov, Nikolai Voinov, Nikolai Zhelynsky and Boris Yankovsky carried out research on ornamental sound tracks. The incredible ANS synthesizer [5][6] by Evgeny Murzin, visualizes sound and vice versa. Oramics [7] is a notable example because it turns a particular shape into pitch, timbre and intensity of sound through 35mm film. In art, these techniques were covered in the works of famous visual music pioneers Oskar Fischinger and extended to Norman McLaren, John Witney, James Davies and Evelyn Lambart. For digital platforms, in the early 90s, Hyperupic [8], an image to sound transducer, was introduced by Chris Penrose as a continuous improvement of Xenakis' UPIC system [9]. Metasynth[3], a successor of Hyperupic [8], offered a unique sound making environment where we paint sound. Monalisa Application [10] interprets binary codes as sound. These examples drove us to explore new sonic experiences. In installation art, Scott Arford's Static Room[4], Granular Synthesis's Lux[5] and Noisefields by Steina and Woody Vasulka[6] are worth noting here. In addition, Atau Tanaka showed the transition between a photograph and sine wave in Bondage [11]. Shawn Greenlee used a digital microscope to scan hand-drawn paintings in his work Impellent along with his graphic waveshaping technique [12]. When it comes to image scanning methods, Probing [13] and Raster Scanning [14], termed by Yeo, are representative scanning frameworks. *Sonifyd* took a similar approach with Probing [13] to allow users to determine the location in line if they want.

Levin's audiovisual performance tool [15] is worth noting because this work is based on free-form image sonification for the real time performance that the direction seems quite similar to my approach. A Stead et al. designed a graphic score system [16] that can be interpreted via cellphone camera and a multi-touch input instrument called ILLUSIO [17] that reads hand drawn sketches for musical expression was introduced. These works exemplify how graphic elements can be associated with sound manipulation. An iOS synthesizer app NAKANISYNTH [18] turns hand-drawn sketches into sound waves and creates amp envelope curves. More recently, a visual score scanner called CABOTO [19] was published in 2018. The creator of CABOTO developed visual scores for music composition as well as scanning system for the visual score.

In music industry, the latest software like Audiopaint[7], Coagula[8], Kaleidoscope[9] and Photosounder[10] can be considered as close relatives to *Sonifyd* because they all are sound design softwares controlled by images. However, my approach was to focus not only on sound design but on the dynamic visual representation to provide multi-sensory experience. The scanning method that I used can be understood as a scanned synthesis [20], however, my algorithm is not targeting to adopt a physically inspired model.

3. IMPLEMENTATION

Processing [21], Syphon [22], MaxMSP, and Lemur [23] are utilized for implementation of this work. Processing sketches travel to MaxMSP for both sonification and scanning process visualization via Syphon, an open-source real time video sharing application. *Sonifyd*'s MaxMSP patch supports two projectable screens so that the system can display both Processing sketches and their corresponding line scanning process. (See Figure 1.)

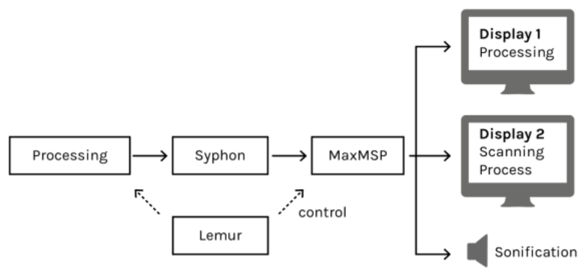

Figure 1: Schematic diagram of *Sonifyd*

3.1. Graphics

Sonifyd adopts an open source programming language Processing for the visual component. Processing is widely used among artists as well as interaction/visual designers thanks to its greater accessibility and ease of use. Processing has been a long time favorite when it comes to computer

[1] https://www.ted.com/speakers/neil_harbisson
[2] https://baranoff-rossine.com/optophonic-piano/
[3] http://www.uisoftware.com/MetaSynth/
[4] www.recombinantfestival.com/2017/project/scottarford/
[5] www.epidemic.net/en/art/granularsynthesis/proj/lux.html
[6] www.vasulka.org/Videomasters/pages_stills/index_42.html
[7] http://www.nicolasfournel.com/?page_id=125
[8] https://www.abc.se/~re/Coagula/Coagula.html
[9] https://www.2caudio.com/products/kaleidoscope
[10] https://photosounder.com/

programming for artists [24][25][26]. I pursue minimalistic graphic design expression in connection with my color-sound sonification strategy because minimalism in graphic design maximizes efficiency of visual communication and this approach can be applied for the same purpose, efficiency of sonic communication. Inbar et al. [27] proved that the minimal graphic expression recorded high acceptance rate among people to information visualization. The definition of sonification is 'the use of nonspeech audio to convey information [28].' I applied Bauhaus's [29] famous design philosophy "Form follows function". That is to say that sonification strategy can be reinforced by minimalism and my work can be characterized by simplicity of my graphic expression in both visual/sound aesthetics and communication viewpoint.

3.1.1. Interactive Images

I have tested a series of the minimalistic graphics shown in Figure 2 with the current version of *Sonifyd*. For instance, a mono color background with mono color basic shapes and a gradient color background with both mono/gradient colored shapes are examined; basic shapes here include an ellipse, rectangle and triangle. Section 5 includes more details about my future plan regarding these interactive images.

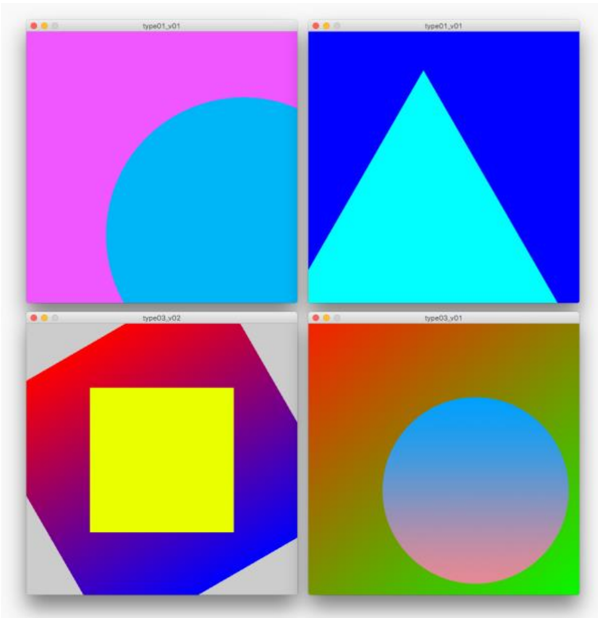

Figure 2: Graphic examples written in Processing

3.2. Image Scanning

MaxMSP's **jit.gl.syphonclient** can mirror Processing sketches and import them to **jit.matrix** in real-time. This system has three **jit.matrix** and two **jit.window** objects for both sonification and visualization purpose. The main **jit.matrix** displays Processing sketches onto **Window1** with the maximum screen size 512x512. The system further offers downsampling capability that leverages built-in Jitter matrix manipulations; as the number of the pixels is reduced, this naturally changes the frequency resolution.

The first **jit.matrix** is divided into two other **jit.matrix** objects for sound representation and showing the scanning process through **Window2** (See Figure 3). The Max's built-in video delay object called **vz.delayr** is connected between these two jit.matrix objects. If this delay object is activated, it simultaneously changes the timbre of the sound; more details will be discussed in section 3.3.4.

There is an invisible scan line moving in either vertical or horizontal position of the screen. 512 pixels per each row/column will determine tone color in connection with the sonification engine. The second **jit.matrix** that displays the scanning process has two arguments called **srcdimstart** and **srcdimend** (See Figure 3), so according to where the scan line is positioned, the corresponding pixels will be shown at the first row/column of **Window2** and the pixels will be stretched to the last row/column of the second screen (See Figure 4). For more flexibility of the visual effect, this system allows users to change the degree of the stretchiness. The bigger the degree is, the smoother the visual transition will be. I attached the images captured when the scanning process was in motion; this includes two stretchiness examples (See Figure 4). This is to provide intuitive experience design that makes people feel a close relationship between images and sounds with the real time scanning procedure as a dynamic imagery presentation.

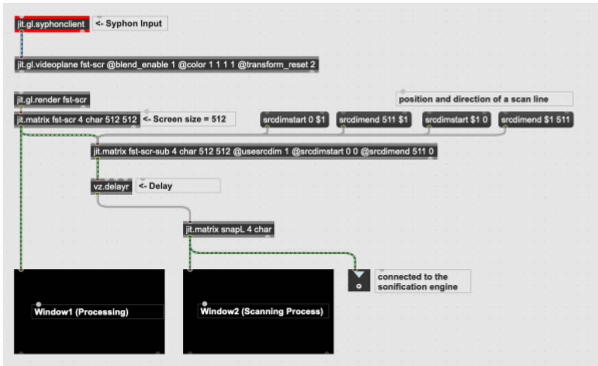

Figure 3: MaxMSP objects for two displays

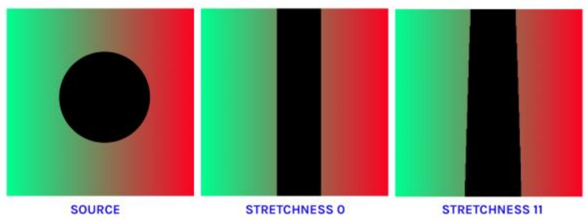

Figure 4: Scanning visualization

3.3. Color-Sound Synthesis Technique and Mapping

The concept of sound design underlies additive synthesis technique. This is mainly because the scan line moves row by row or column by column in parallel with the pixel size of the screen. Additive synthesis is an excellent way to reconcile all pixel data at where the scan line is located. For example, FormSound [30], an additive synthesis-based platform, shows clear tonal changes based on the number of the particles. *Sonifyd* converts 512 pixels in line into sound. Each axis of the screen represents time and oscillator. Software called AudioPaint [31] uses a similar tactic because this software converts pictures into sounds with an additive synthesis technique; one line of the picture serves as an oscillator. But AudioPaint is not real time based and *Sonifyd* has a difference color-sound mapping strategy.

3.3.1. Color-sound mapping

I applied HSL color system to interpret color values into sound. Within ICAD community, *Hue Music* [32] was discussed and hue values from 2D image create timbre. In *Sonifyd*, hue values present frequencies of each partial, and saturation and lightness control pitch shifting. Amplitude of each partial is fixed with the value 0.8(0.0-1.0) to hear each frequency component at the same amplitude level; the attached video example *Demo1-Installation* supports saturation and lightness mapping that are responsible for an octave and gain control; however, there was no significant tonal changes observed.

Hue mapping represents microtonal scales in an octave (See table 1) and the range is 369Hz(F#) to 739Hz(F#); this implies that if two hues are adjacent, beat tones can be heard. It is known that the spectrum of visible light can be within an octave [33]. This is the system's default setting that can be easily adjusted with the minimum and maximum values for more wider timbral flexibility. However, I do not recommend going beyond 5000Hz because it is known that a pitch perception is not accurate above 5KHz [34][35]. The color-sound relationship here is not the main focus at this stage because *Sonifyd* is primarily designed for audiovisual instrument. As musical instrument, the wider the frequency range is, the more tonal flexibility the users experience.

This system's additive synthesis technique has been implemented by the Max object called **oscillators~**, developed by CNMAT, UC Berkeley.

Color	Sound
Hue (0.0-1.0)	Frequency of each partial (369Hz to 739Hz)
Saturation (0.0-1.0) *1.0 is neutral	Pitch Shift B (0 to 2 octaves) *This is because when saturation goes down, the lightness goes up.
Lightness (0.0-0.5) *0.5 is neutral	Pitch Shift A(0 to -2octaves)
Lightness (0.5-1.0) *0.5 is neutral	Pitch Shift B(0 to 2octaves)

Table 1: Color-sound mapping (the main oscillator)

3.3.2. Pulse wave amplitude modulation

For the attached video *Demo1-Installation*, black and white represent the lowest and highest frequency depending on the color-sound mapping. Instead, black and white in *Sonifyd* generate a pulse wave. These colors have no effect on timbre but modulates an amp envelope of the main oscillator (See the wavetable in Figure 5 and refer to LFO in Figure 6). The black area from the right image(B) will turn into 0 and the wavetable modulates amplitude. In Figure 5 below, the red line shows the invisible scan line and the right image(B) represents the scanning window. The idea of using black and white colors to modulate the amplitude comes from graphic design metaphor that black and white signify empty space (like rest in music). If I draw black or white grid/stripe, the image will play a role as a step sequencer.

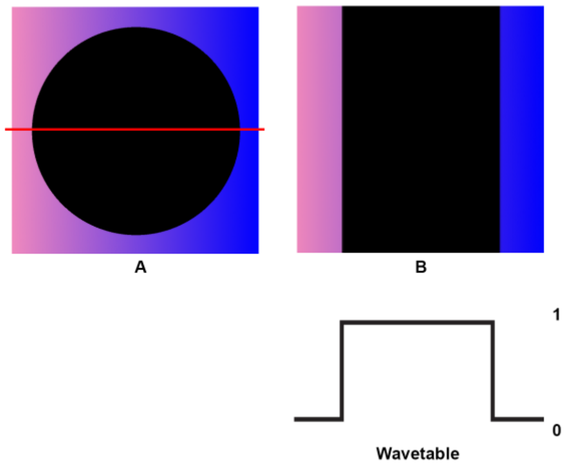

Figure 5: Pulse wave from black and white

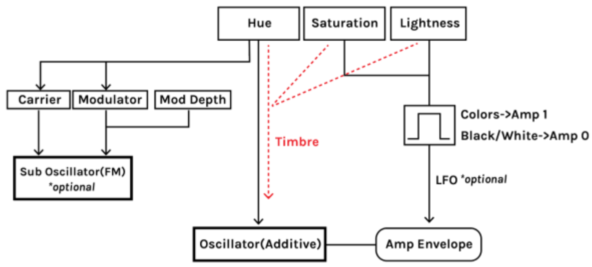

Figure 6: Sound Design

3.3.3. Sub-oscillator

Sonifyd comes with an optional sub-oscillator action to enhance sound character and increase the density of the sound. This is to improve the drawback of an additive synthesis. For example, an additive synthesis makes no tonal difference between the image A and B because they both consist of the same frequency components (See Figure 7).

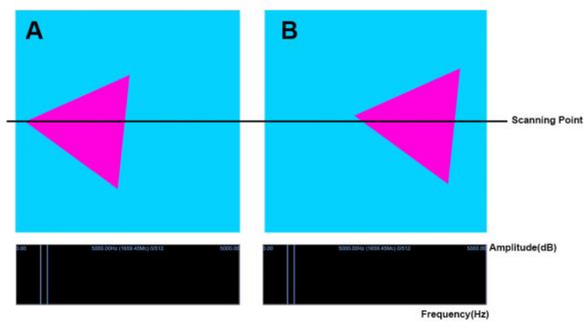

Figure 7: Images that have the same frequency component.

The sub-oscillator is based on frequency modulation synthesis and the carrier frequency goes two octaves below based on the lowest frequency of the main oscillator. However, this mapping is customizable according to users' preferences; it goes down from one to three octaves.

Hue values draw a wavetable for the modular frequency of the sub-oscillator (See Figure 6) and the frequency of the modular frequency is determined by the lowest frequency of the main oscillator; the modular frequency is three octaves lower than the lowest frequency of the main oscillator. This sub-oscillator can be activated or deactivated.

FM	The frequency range of the main oscillator
Carrier Frequency	Two Octaves below from 369Hz (the lowest) *Customizable
Modulator Frequency	Three Octaves below from 369Hz (the lowest) *Customizable
Modulation Depth	Fully Flexible (between 0 to 1000)

Table 2: Color-sound mapping (the sub-oscillator)

3.3.4. *Audio reverb and video delay*

Sonifyd has an optional audio reverb and video delay effect. If a video delay is engaged, it makes a visual reverberation and naturally creates additional color tones (See Figure 8). This means that it consistently increases the number of partials of the synthesized sound. The amount of the video delay corresponds to the amount of audio reverb. My future plan regarding sound and visual effect is described in Section 5.

Figure 8: A delay effect that is applied into the scanning system.

3.4. Control Interface

Processing sketches can be accessed with Lemur for the real time practice/performance. Lemur is an iphone/iPad MIDI/OSC compatible controller interface to control graphic attributes such as shapes, size, position or colors. Further, Lemur allows users to switch the scanning direction between horizontal and vertical, and increase/decrease scanning speed in MaxMSP. In Figure 9, a user can change RGB values of background/shape colors, rotate shapes, scale the size of the shapes, and move between different Processing sketches if multiple Processing windows are running at the same time. Using touchable interface as a controller is not a new technology these days. As *Sonifyd* is developed mainly for real-time audiovisual performance, a control interface is needed. Hardware MIDI controller may work for this purpose, but it is difficult to customize. Lemur is the most reasonable choice to access *Sonifyd* because OSC-based controllers like Lemur or TouchOSC[1] provide more flexible graphical control interface. A brief example of the interactive scenario (Demo3) is shown in the video sample I linked.

Figure 9: Lemur control interface

4. DESIGN CRITERIA

Sonifyd is firstly designed for my own multimedia performance tool. In this paper, I aim to introduce my audiovisual instrument and explain how I designed it. The current version of *Sonifyd* is still at the early phase of my longer research. Considering this, I performed self-evaluations focusing on sound design and controllability perspective. First, the more color values the scan line has, the richer sound this system will create. Since gradient colors contain a wider sound spectrum range in comparison to plain colors, a pleasing sound with the smooth visual and sonic transition can be heard if gradient colors are shown. This is a natural character of an additive synthesis technique. Second, Syphon causes a little communication delay between MaxMSP and Processing. The delay does not give rise to a critical issue so far, however, it will speed up the system if there is a way to bring Processing into MaxMSP without Syphon. I have posted this issue on the online community, but clear solution does not exist yet. Third, additive synthesis is not appropriate to distinguish the position of the shape. For example, a magenta triangle on the left side of the screen and another magenta one on the right side of the screen with the same background color will create the same timbre (See Figure 7). This is why I applied the sub-oscillator described in section 3.3.3. It significantly helps to solve this issue, but another question arose. This is about how many times these modulations must be triggered along with the speed of the scanning process; further study of this issue will be required. As I previously mentioned in section 3.3.3., this modulation frequency is determined by the lowest frequency of the main oscillator. However, the sound differences between two images in Figure 7 are subtle. If I can find out another useful way to clarify these differences with the same scanned synthesis I used, *Sonifyd* project can take another step forward and I will be soon ready for auditory icon study [36][37][38] I want to explore.

[1] https://hexler.net/software/touchosc

5. CONCLUSION AND FUTURE WORK

Sonifyd that has been applied an additive sound synthesis technique and wavetable-based sound modulation [12][39] determines timbre and creates various tonal characters by scanning images. In addition, since there is no absolute connection between color and sound frequencies, *Sonifyd* provides an improvisational and experimental sound design environment with the customizable mapping interface. This study was a good starting point and found a great potential that will lead me to more advanced types of instrument to cultivate a unique sound making and immersive synesthetic audiovisual experience. Figure 10 shows how I exhibited the previous version of *Sonifyd* using an immersive projection space.

This section lists my future plan to expand the functionality and develop other variant platforms. First, different sound synthesis techniques, FM synthesis, subtractive synthesis, and wave shaping synthesis, will be applied to design the main oscillator. Second, further experiments on reverb and delay will be performed to see how these spatial sound effects can be utilized as both sonification variables and visualization effects. Third, Processing sketches will be widely expanded following graphic design themes such as the sound of grid system, the sound of geometric shapes, etc. These themes will be designed for both interactive audiovisual performance and media art installation purpose. Fourth, I will compare each graphic-sound mapping model with the same visual themes and analyze the results with a question of what sound synthesis strategies best represent a gradient circle on a mono color background for instance. This approach will lead me to investigate how the minimalistic graphics can act as visual scores as well. Fifth, *Sonifyd* will support multiple Processing sketches running all together and each sketch will be multi-layered to form an ensemble; different sonification strategies can be applicable to them. Lastly, a tempo sync function that is compatible with other hardware/software synthesizers, DAWs and step sequencers can be necessary to enhance the capabilities that allow more practical, flexible, and wider musical expression as a novel sonification-based instrument. The scanning method that I used has lots of precedents (See Section 2) and I may need to consider to use another scanning method such as a spot-mapping method that SPOTTY [40] and Voice of Sisyphus [41] used. Solving questions listed above is my absolute priority.

Figure 10: Installation using an immersive projection space.

6. REFERENCES

[1] M. Haverkamp, Synesthetic design: Handbook for a multi-sensory approach. Walter de Gruyter, 2012.

[2] M. Wright and A. Freed, “Open SoundControl: A New Protocol for Communicating with Sound Synthesizers.,” in ICMC, 1997.

[3] C. Roads and J. Strawn, Graphic Sound Synthesis. The computer music tutorial, vol. 32, no. 6. MIT press, 2003.

[4] R. A. Khan, M. Jeon, and T. Yoon, “‘Musical Exercise’ for people with visual impairments: A preliminary study with the blindfolded,” 2018.

[5] T. Y. Levin, “‘Tones from out of Nowhere’: Rudolph Pfenninger and the Archaeology of Synthetic Sound,” Grey Room, vol. 12, pp. 32–79, 2003.

[6] S. Kreichi, “The ANS synthesizer: Composing on a photoelectronic instrument,” Leonardo, pp. 59–62, 1995.

[7] J. Hutton, “Daphne Oram: innovator, writer and composer,” Organised Sound, vol. 8, no. 1, pp. 49–56, 2003.

[8] C. Penrose, “Hyperupic.” 1992.

[9] H. Lohner, “the UPIC system: A User’s Report,” Comput. Music J., vol. 10, no. 4, pp. 42–49, 1986.

[10] K. Jo and N. Nagano, “Monalisa:" See the Sound, Hear the Image",” Proc. 8th Int. Conf. NIME, pp. 6–9, 2008.

[11] A. Tanaka, “Biomuse to bondage: Corporeal interaction in performance and exhibition,” in Intimacy Across Visceral and Digital Performance, Springer, 2012, pp. 159–169.

[12] S. Greenlee, “Graphic Waveshaping,” in Proceedings of the International Conference on New Interfaces for Musical Expression, 2013.

[13] W. S. Yeo and J. Berger, “A framework for designing image sonification methods,” Proc. 11th Int. Conf. Audit. Disp. (ICAD 2005), pp. 323–327, 2005.

[14] W. S. Yeo and J. Berger, “Raster Scanning-A New Approach to Image Sonification Sound Visualization, Sound Analysis and Synthesis,” Proc. ICMC 2006, pp. 309–314, 2006.

[15] G. Levin, “Painterly Interfaces for Audiovisual Performance,” MIT Media Lab., pp. 1–151, 2000.

[16] A. G. Stead, A. F. Blackwell, and S. Aaron, “Graphic Score Grammars for End-Users,” New Interfaces Music. Expr., pp. 196–200, 2011.

[17] J. Barbosa, F. Calegario, V. Teichrieb, G. Ramalho, and G. Cabral, “Illusio: A Drawing-Based Digital Music Instrument,” NIME ’13 Proc. 2013 Conf. New Interfaces Music. Expr., pp. 499–502, 2013.

[18] K. Nakanishi, P. Haimes, T. Baba, and K. Kushiyama, “NAKANISYNTH: An Intuitive Freehand Drawing Waveform Synthesiser Application for iOS Devices,” Proc. Int. Conf. New Interfaces Music. Expr., vol. 16, pp. 143–145, 2016.

[19] R. Marogna and J. Van Stolberglaan, “CABOTO : A Graphic-Based Interactive System for Composing and Performing Electronic Music,” pp. 37–42, 1930.

[20] R. Boulanger, P. Smaragdis, and J. ffitch, “Scanned Synthesis: An introduction and demonstration of a new synthesis and signal processing technique.,” in ICMC, 2000.

[21] B. Fry and C. Reas, “Processing. org,” Process. org, 2010.

[22] “Syphon.” [Online]. Available: http://syphon.v002.info/. [Accessed: 27-Mar-2019].

[23] "Lemur – Liine." [Online]. Available: https://liine.net/en/products/lemur/. [Accessed: 27-Mar-2019].

[24] H. Bohnacker, B. Gross, J. Laub, and C. Lazzeroni, Generative design: visualize, program, and create with processing. Princeton Architectural Press, 2012.

[25] M. Pearson, Generative Art. Manning Publications Co., 2011.

[26] D. Shiffman, The Nature of Code: Simulating Natural Systems with Processing. Daniel Shiffman, 2012.

[27] O. Inbar, N. Tractinsky, and J. Meyer, "Minimalism in information visualization: attitudes towards maximizing the data-ink ratio.," in ECCE, 2007, vol. 7, pp. 185–188.

[28] P. C. Gregory Kramer, Chair; Bruce Walker and Terri Bonebright; Perry Cook; John Flowers; Nadine Miner; John Neuhoff, "The Sonification Report: Status of the Field and Research Agenda." [Online]. Available: http://www.icad.org/websiteV2.0/References/nsf.html. [Accessed: 27-Mar-2019].

[29] L. Moholy-Nagy, The new vision: fundamentals of Bauhaus design, painting, sculpture, and architecture. Courier Corporation, 2012.

[30] S. Park and W. Joo, "FormSound: A particle formation-based audiovisual interface," in 2017 ICMC/EMW - 43rd International Computer Music Conference and the 6th International Electronic Music Week, 2017.

[31] "Nicolas Fournel » AudioPaint." [Online]. Available: http://www.nicolasfournel.com/?page_id=125. [Accessed: 27-Mar-2019].

[32] D. Payling, S. Mills, and T. Howle, "Hue music-creating timbral soundscapes from coloured pictures," 2007.

[33] "Pitch/Frequency Related to Color." [Online]. Available: http://wagneric.com/audiocolors.html. [Accessed: 27-Mar-2019].

[34] C. Roads and J. Strawn, Perception of Frequency. The computer music tutorial. MIT press, 1996.

[35] E. D. Schubert, Psychological acoustics, vol. 13. Hutchinson Ross Publishing Company, 1979.

[36] K. van den Doel et al., "Geometric shape detection with soundview," 2004.

[37] M. Cooley, "Sound+ image in computer-based design: learning from sound in the arts," 1998.

[38] E. D. Mynatt, "Designing with auditory icons," 1994.

[39] C. Roads and J. Strawn, Waveshaping Synthesis. The computer music tutorial. MIT press, 1996.

[40] G. Evreinov, "Spotty: imaging sonification based on spot-mapping and tonal volume," 2001.

[41] I. Conference and A. Display, "VOICE OF SISYPHUS : AN IMAGE SONIFICATION MULTIMEDIA INSTALLATION Ryan McGee , Joshua Dickinson , and George Legrady Media Arts and Technology University of California , Santa Barbara," Int. Conf. Audit. Disp., pp. 141–147, 2012.