PORTAL: An Audiovisual Laser Performance System

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ABSTRACT

PORTAL is an interactive performance tool that uses a laser projector to visualize computer-generated audio signals. In this paper, we first offer an overview of earlier work on audiovisual and laser art that inspired the current project. We then discuss our own implementation, focusing not only on the technical issues related to the use of a laser projector in an artistic context, but also on the aesthetic considerations in dealing with the translation of sounds into visuals, and vice versa. We provide detailed descriptions of our hardware implementation, our software system, and its desktop and mobile interfaces, which are made available online. Finally, we offer the results of a user study we conducted in the form of an interactive online survey on audience perception of the relationship between analogous sounds and visuals, which was explored as part of our performance practice.

Author Keywords

Audiovisual art, sound-image interaction, multimodality, laser projection

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces

1. INTRODUCTION

Advances in technology over the last century has ushered in a variety of artistic practices. New hardware and software technologies made tools, such as microcontrollers and programming languages, that were initially exclusive to scientific communities accessible to personal use [8]. The same technological progression has also caused many tools to become obsolete over the years. However, artistic practices are not necessarily bound by trends in technology. For instance, the artist Stanislaus Ostoja-Kotkowski utilized the laser projector as a medium to "free his imagination from the creativity limits of traditional media" [11]. This is a strategy that can be observed in the works of many contemporary artists [4], where the constraints proposed by using cheap, accessible, and even archaic technologies are utilized as an artistic drive [1].

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With the *PORTAL* project, we explore the translational links between sound and visuals through the use of oscilloscope plotting and laser projection. We utilized the challenges proposed by operating a mechanical laser projector as an aesthetic constraint when exploring the unmediated translation of audio signals into visuals through oscillography. Based on these technologies, we implemented hardware and software tools towards an artistic project on the fluid relationship between sounds and images. Furthermore, we used the findings of our performance practice to prepare a survey that investigates the audience perception of this relationship.

2. RELATED WORK

Mathematicians and physicists, such as Nathaniel Bowditch and Jules Antoine Lissajous, have investigated the mathematical representation of complex harmonic motions in the 19$^{\text{th}}$ century. Their findings have been utilized in artworks by pioneering artists such as Herbert Franke, John Whitney and Nam June Paik [10]. In 1969, the artist-mathematician Ben Laposky proposed that electronics would inevitably be used in the creation of art [10]. Parallel to the development of electronic music in the 1950s [2], Laposky used scientific instruments, such as cathode ray oscilloscopes, signal generators, and additional custom circuitry, to create visual artworks, which he called *Oscillons*. Laposky highlighted an analogous behavior between auditory and visual phenomena through *Oscillons*' wave-like nature.

The visual artist Herbert Franke, who was also a mathematician, similarly experimented with oscillographic waveforms [8]. The artist captured oscillographic figures by using long exposure photography, and presented them as fixed images.

More recently, the artist Edwin Van der Heide's work *LSP* (2003-2009) investigates the spatial diffusion of sound and light waves. In his laser performances, the artist examines the spectral aspects of sound through slowly evolving rhythmic structures while at the same time meticulously plotting visuals.

Laser Show is a 2007 work by the artist Robin Fox, who explores the multimodal experience of lasers, light and sound. The work defines the space through sonic vibrations and the movement of light beams [7]. The result is a performance that can be visually associated with rave culture. The sound elements used in this project exhibit noise and glitch aesthetics. Similar to Van der Heide's *LSP*, the laser projector in Fox's work is faced towards the audience.

In his work, *Oscilloscope Music* (2013), the artist Jerobeam Fenderson utilizes oscilloscopes and *Pure Data* to compose oscillographic videos published online. In these works, the visual domain can be described as more dominant and representational, while the sounds remain abstract. The artist generates a visual language through juxtaposition of geometric shapes, noisy visuals and representational forms.

Finally, Robert Henke's audiovisual performance *Lumière* (2013) uses oscillographic imagery, laser projection and sound. Henke utilizes *Max for Live* [9] to perform elaborate laser shows that are based on the real-time interaction between dance music and vector graphics. Using three RGB laser projectors, Henke articulates not only the performance space but also various layers of his music.

3. THE PORTAL SYSTEM

PORTAL relies on an audiovisual translation rather than a cross-modal mapping of performance data. This translational approach creates a poietic turbulence between the sounds and the images that make up a *PORTAL* performance. The artist Ian Andrews describes such practices, where images become “a direct consequence of the audio signal” [1], as the purest form of audiovisual art. Similarly, the artist Robin Fox characterizes the transformation of these two domains into one another as the most interesting facet of audiovisual art [7]. The audiovisual translation in *PORTAL* relies on a complex iterative feedback loop, in which both the artist and the audience evaluate the momentary aesthetic hierarchies between the sounds and the images. The artist reacts to these fluctuations in hierarchy and balances the relationship between sound and visuals accordingly. In agreement with the artist Roger Dannenberg's views on audiovisual art [5], we consider each modality of a *PORTAL* performance as being an integral part of the total experience, rather than an accompaniment to a dominant modality.

In *PORTAL*, we initially explored the feedback loop between sounds and images in the form of short excerpts where we plotted primitive shapes using audio signals. Such exercises have inherently shaped our performance system. Each *PORTAL* performance begins with the introduction of such primitive elements (e.g. pure tones in the audio domain and basic geometries in the visual domain), which gradually evolve into more complex structures. Dynamic visual entities are created by the oscillographic translation of audio signals that are passed through a series of signal processors. To achieve a complexity of sound and moving images, we utilized frequency modulation, which was applied to the audio domain by the composer John Chowning in the 1960s [3]. This strategy helped us to construct elaborate web-like quasi-3D structures.

Figure 1: A photo from a *PORTAL* performance

We have implemented 32 FM modules inside a 16-step sequencer, with stereo-separated steps that consist of an individual carriers. This stereo separation causes emergent patterns in the audiovisual output. Furthermore, the system uses stochastic methods to determine carrier and modulator frequencies, as well as modulation indexes. Although each performance originates from the same primitive sounds and visual shapes, the artist's reaction to the system's stochastic decisions render each performance unique. The relationship between the performer and the system is based on an action/perception feedback loop [12], where the performer intervenes with the system and the system responds to these interventions. This continuous dependency between the human and the computer resumes until the performer decides to finalize the performance.

In the words of the famous film director Sergei Eisenstein *“art is always conflict.”* [6]. The causal relationship between the auditory and visual modalities can become obfuscated by the complex nature of frequency-modulated waveforms. Such conflicts may motivate the artist to take actions to simplify the correlation between the sounds and the visuals. From the performer's perspective, dictating or disturbing this causality becomes a propelling strategy during a performance. Altering the carrier frequencies, applying drastic pitch changes, introducing noise and glitch elements are aimed at articulating the immediate relationship between the two modalities in a *PORTAL* performance. Such cues are intended to help the audience recognize the synchronicity between the sounds and the visuals.

Laser projectors function based on a similar principle as X-Y oscilloscopes, which are commonly used to visualize waveforms on a 2D plane for scientific measurement purposes. Unlike a screen projector, laser projectors therefore can only draw vector outlines of images. Exploiting the perceptual threshold of the human eye, the plots of a laser projector can be made to appear as polygonal forms when drawn fast enough. This quality of laser plotting is analogous to the temporal nature of sound, where forms become apparent over time. Furthermore, we utilized the mechanical constraints of our medium as features of the performance. For instance, since a laser projector cannot draw outside its mechanically defined boundaries, we used overdriven audio signals to plot distorted, or jagged, visual forms.

4. IMPLEMENTATION OF PORTAL

4.1 Hardware

The hardware components of *PORTAL* include a laptop computer, a digital-to-analog converter (DAC), a custom-built ILDA interface, and a laser projector. We used a *MOTU UltraLite-mk3 Hybrid* DAC to output not only AC audio signals, but also DC signals, which are necessary to control the galvanometers inside the laser projector. 2 of the 5 outputs on the DAC were used for stereo sound output. The remaining outputs were used to control horizontal and vertical movements of the projector mirrors, and the intensity of the laser beam.

For projection, we used a monochromatic green laser projector with ILDA connectivity, which is an industry standard analog input format for controlling X-Y positioning and RGB intensity in commercial laser projectors. The left and right audio channels can be directly connected to speakers using TS cables. It is necessary to convert the output of the three remaining TS cables to DB-25 pin output to adapt to the ILDA input. Since we only manipulate the horizontal and vertical axes, and the intensity of the beam, we utilized X+, Y+, G+, and ground pins of the female end of a DB-25 connector.

The parametric control of the projector is achieved with

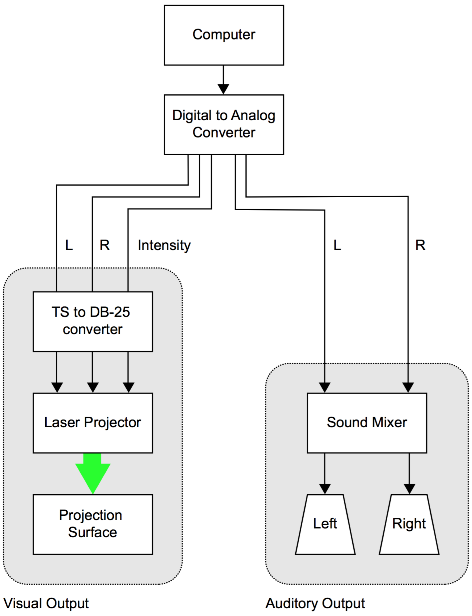

Figure 2: Hardware diagram of *PORTAL*

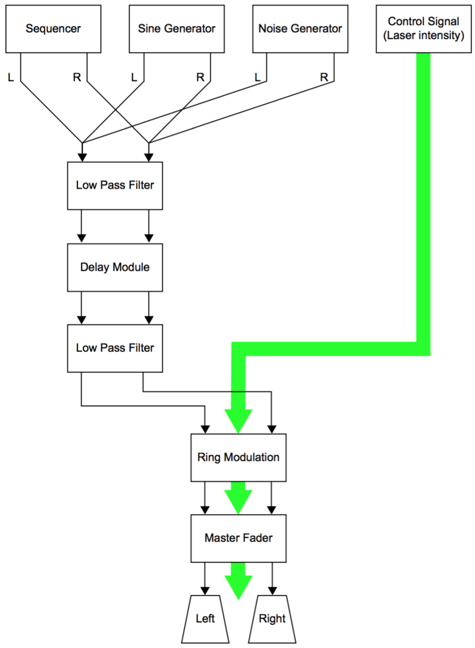

Figure 3: Signal flow diagram of *PORTAL* software

signals between +/-7V DC, which determines the horizontal and vertical reach of the beam. Since the DAC we used is able to output +/-4.25V, it is necessary to either use a step-up transformer on the signal input level, or a lens on the projector's laser output to extend the reach of the beam. Since the optical method, which is independent of the mechanical constraints of the projector, gives us more flexibility, we utilize a custom attachable lens during performances.

In our performances, we have experimented with various screening methods. We have observed that projecting onto a separate screen causes a segmentation between the performance space and the visuals. Given the continuity between the sounds and the images of *PORTAL*, we found it necessary to project onto existing surfaces of the performance space rather than using an articulated screen. The visuals therefore act as an intervention to the space like a graffiti rather than a framed painting, in the same way the sounds occupy the acoustic space. We have also observed that utilizing existing architectural and interior design elements of a performance venue, such as columns, drapes and textured walls, can be used to add an extra dimensionality to the projections that wrap around these forms.

4.2 Software

PORTAL's software, which can be downloaded for free at `http://github.com/portalproject/`, is developed using the multimedia programming language Max[1], which allowed us to implement both the audio and the video components of our project in a single environment. Our software consists of several components, including a 16-step sequencer with individual stereo frequency modulators, tone generators, and chains of diverse effects, such as delay, ring modulator and bi-quadratic filters. While the master audio output controls the horizontal and vertical scanning of the laser beam, an auxiliary output manipulates the laser intensity, as seen in Fig. 3.

For a description of the user interface, we will refer to the numeric indicators on Fig. 4. This description also reveals how certain design decisions we made originate from a visual perspective while others are rooted in the auditory domain.

PORTAL's 16-step sequencer encapsulates individual FM modules for left and right channels. When initiated, the system determines random carrier frequencies, modulation indexes, and a modulation frequency. Using the row of knobs at (9), the performer can manipulate the modulation indexes. The modulation frequency controls at (3) include a knob for parametric control and a button, which assigns a random value to this parameter. The latter also assigns a random frequency ratio between the left and right channels from 1 to 5. This adds a layer of dynamism to both the sounds and the visuals. A fine tune button at (4) can be used to increment and decrement the modulation frequency by 10 Hz ramps. This modulation frequency also serves as a reference point for an independent sine wave generator, whose gain can be controlled with the UI elements at (5). This sine wave generator is used to create basic Lissajous curves. The channels of this independent signal generator can also be swapped either continuously with a knob or discretely with a button, as seen at (7). The volume of a white noise generator can be controlled with (6). The output of the step sequencer, the sine wave generator, and the white noise generator are summed to produce the final audiovisuals.

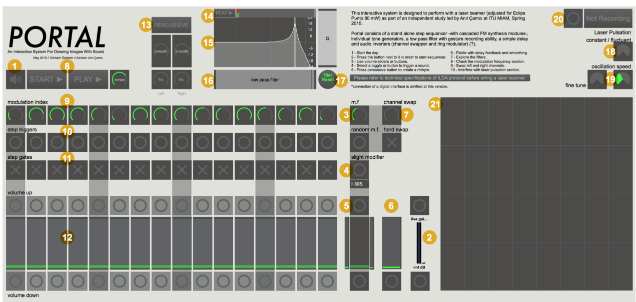

Figure 4: Interface of *PORTAL* software

The 16-step sequencer can be initialized and controlled with the transport buttons at (8). The performer can trig-

[1]http://www.cycling74.com

ger a desired step individually at (10) without initiating a sequence. After the initialization, each step can be gated individually with toggles at (11). The performer can also control the volume of each step by using either the faders or the volume automation buttons at (12). Rhythmic patterns can be added to the signal by enabling the percussive mode and controlling a series of delays with the UI elements at (13). This module is placed between two low pass filters which can be controlled with (15) and (16). The performer's interactions with the first filter are recorded and can be played back using the button at (14). A display next to this button reports the recording and playback state. The filter can be reset with the button at (17). The second filter controller at (16) is used to low-pass the entire signal before output. The pulsation knob at (18), which controls a modulation of the laser beam intensity, also acts as a dry/wet knob for ring modulation in the auditory domain. Its oscillation speed can be tuned with the two knobs at (19). Lastly a digital oscilloscope at (21), allows the performer to monitor the visual output. A fader at (2) controls the master gain of the system. A record button at (20) stores both the audio output of the system and the laser intensity values as two separate AIFF files, which can then be used the playback a performance in its entirety.

Although our system allows the performer to control the UI with mouse input, we have also designed an accompanying touch-based interface using Lemur, which is a MIDI & OSC controller app for iOS and Android. The mobile UI, which can be downloaded from the github repo provided earlier, divides the desktop interface into several screens to allow for touch interactions. Furthermore, the multi-touch capabilities of this interface allows for the concurrent manipulation of various parameters.

5. SURVEY EVALUATION

To explore the audience perception of the audiovisual translations we explored while developing the *PORTAL* system, we conducted a survey. The survey consists of 30 questions. The question types include multiple choice, audiovisual pairing, complexity rating and free-association.

5.1 Apparatus

PORTAL survey was designed for the web browser using the JavaScript library p5.js. For data collection, a web-based form service was used. The participants were advised to use headphones during the survey.

5.2 Participants

107 people, aged between 19 and 54, took the survey between December 7th and 15th, 2015. 49 participants were male, while 58 participants were female. Participants were from Turkey, Canada, Netherlands, Austria, US and France.

5.3 Question types

Timbre-Shape Matching: This question type examines the relationship between basic visual shapes and a steady waveform. In these questions, stereo separated saw, sine and square waves were used to create dynamic visuals, as seen in Fig 5. Based on different sounds in each question, the participants were expected to select one of the three oscillographic images.

Movement Matching: This question type explores the relationship between a visual motion and a sonic gesture. In each question, participants were asked to pick one of three sonic gestures based on the provided dynamic image. Across three questions, each gesture individually displays a change in panning, volume or pitch. The visuals displayed left-right, up-down, and circular motions.

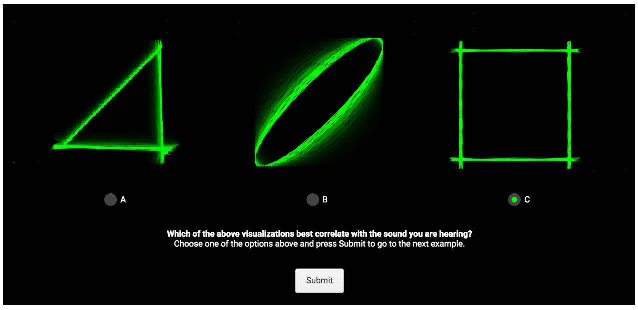

Figure 5: Interface for the timbre-shape matching questions

Temporal Matching: In these questions, a dynamic oscillographic image and a slider are presented to the user as seen in Fig. 7. The user is expected to move the slider to control the auditory output. In doing so, the user is able to change the beating frequency between two tones to match its temporal pattern with that of the visual, which is drawn based on the same beating phenomenon.

Sound Complexity Rating: This type of question asks participants to rate the perceived complexity of a sound element in relation to another one. In each question two FM modules with different modulation parameters are compared. Carrier frequencies, which are assigned to left and right channels individually, are used to create comparisons of four different features, including auditory beating, pitch difference, tonal separation and noise. A rating scale from -5 to +5 is provided for designating the complexity.

Visual Complexity Rating: This question type investigates the perceived complexity of a dynamic oscillographic image in relation to another one. In the first four questions, four FM modules from the *Sound Complexity Rating* questions are used. In the fifth question, an FM-based visual was compared to another one generated with white noise. Similar to sound complexity questions, a rating scale from -5 to +5 is used for designating the complexity, as seen in Fig 6.

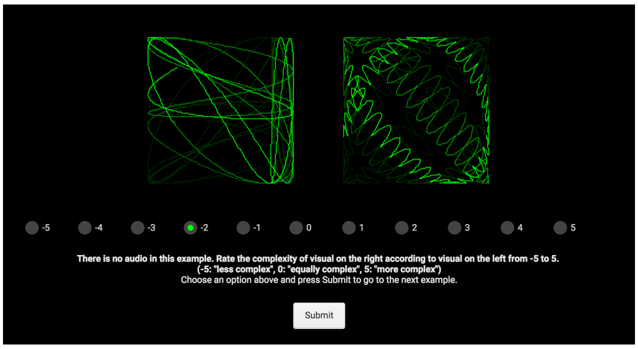

Figure 6: Interface for the visual complexity rating questions

Free-association: This question type examines the mental associations formed by the participants in response to pre-recorded excerpts. The participants are expected to verbalize their impressions in the form of short descriptors and to type them into a text box. Four audiovisual excerpts from previous *PORTAL* performances were utilized.

5.4 Results & Discussions

Timbre-Shape Matching: Table 1 shows the distribution of user responses to the timbre-shape matching questions.

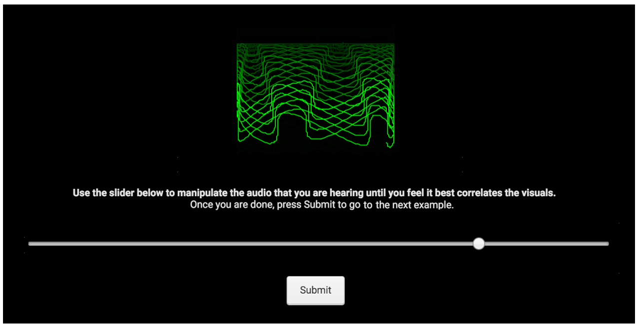

Figure 7: Interface for the temporal matching questions

A, B and C correspond to the presented visual forms, which were repeated in each question, as seen in Fig. 5. Leftmost column on the table lists the sounds that were played in each question in the order they were presented.

Table 1: Distribution of answers for the timbre-shape matching questions.

	A (Triangular)	B (Elliptic)	C (Rectangular)
Square wave	52.4%	12.4%	%35.2
Saw wave	43.1%	45.3%	%11.6
Sine wave	36.7%	51.9%	%11.4

The results show that while the participants were inclined to map sounds with increased partials (i.e. saw and square waves) to visual forms with edges, there was not a clear differentiation between the oscillographic outputs of these wave forms. There is, however, a clear preference for mapping the sine tone and its elliptic output. Knowing that this was the final example from this question type, it can be assumed that users had a reference point from the first two questions, which helped them better correlate the sound and its oscillographic representation. This finding informs our practice about the possibility of priming the audience during the course of a performance to incite a clearer sense of mapping between the sounds and the visuals.

Movement Matching: Table 2 displays the distribution of responses to the movement matching questions. The leftmost column lists the three visual motions that were displayed in each question in the order they were presented. Horizontal movement refers to a dot oscillating on the horizontal axis. Vertical motion refers to a visual form that moves up and down on the vertical axis. Finally, circular motion refers to a dot that oscillates on a circle. The sounds used in these questions included a sound that oscillates at 0.5Hz between left and right channels, a second sound whose amplitude oscillates at 0.5Hz between minimum and maximum volume levels, a third sound whose pitch oscillates at 0.5Hz between 40Hz and 440Hz, and a fourth sound, which did not display any changes over time. The latter is labeled as "stable" in the results below. Three out of four sounds were provided as choices in each question in the order they appear on Table 2.

The results show that the participants showed a preference towards associating horizontal motion in the visual domain to changes in sound panorama, and vertical motion in the visual domain to changes in amplitude. A clear preference was not evident in the circular motion question, with results almost evenly distributed across stable, pitch oscillation, and amplitude oscillation sounds.

Temporal Matching: Figure 8 shows the distribution

Table 2: Distribution of answers for the movement matching questions.

	Panorama	Pitch	Stable
Horizontal	63.1%	31.1%	5.8%
	Amplitude	Panorama	Stable
Vertical	47.1%	37.6%	15.3%
	Pitch	Stable	Amplitude
Circular	39.2%	31.6%	29.1%

of responses to each question in this category, with the X-axis showing the frequencies selected with the slider, and the Y-axis showing the number of participants for each selection. Visible peaks in these graphs generally overlap with the visual beating frequencies used in the excerpts, which are highlighted with a needle in the graphs. This implies that the participants were largely able to map the temporal fluctuations in the sounds to those in the visuals.

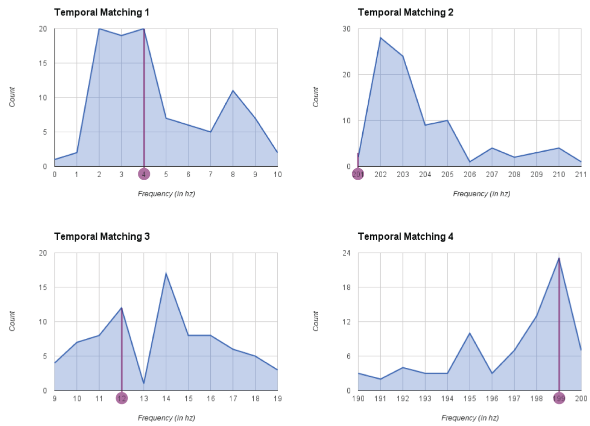

Figure 8: Graphs for temporal matching results

Sound Complexity Rating: Fig. 9 shows the results for this question type. In the first question, two FM sounds, whose beating characteristics differed on the basis of their carrier frequencies were compared. The ratings peaked around +1 and +2, which implies that changes in beating characteristic did not greatly contribute to variations in perceived complexity. In the second and fourth questions, differences in modulation frequencies were used to create pitch differentiations between the two sounds. In the results, either a clear preference was not evident or it focused on a neutral rating. In the third question, where white noise was provided against an FM sound, a peak at +5 rating is visible, highlighting the perceived complexity of white noise. In the fifth question, the first sound is a monophonic FM sound, while the second one is a combination of two FM sounds with distinct fundamental frequencies. A preference towards describing the latter as more complex is also evident in the results.

Visual Complexity Rating: Four out of five questions are derived from the same FM modules that are used in the sound complexity questions with a final one based on two modulation ratios used in our performances. The results are shown in Fig. 10. In the first question, the difference in carrier frequencies affected the rotation of the visuals. Comparison of a stable visual versus a visual that rotates on the horizontal axis is presented in the first graph. The result correlates with the first sound complexity question, with a preference on neutral rating. In the second question, a visual with a complex curvature and a visual with

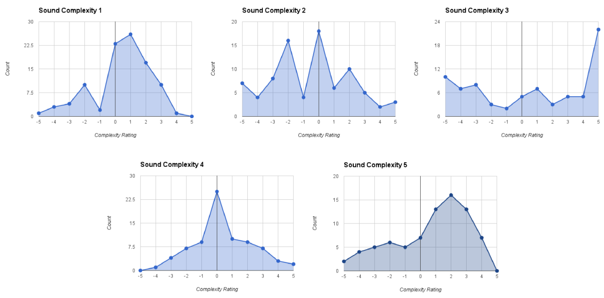

Figure 9: Graphs for sound complexity results

a basic geometry are compared. The distribution is almost even without a clear preference, which also correlates with the corresponding sound complexity example. In the third question, a complex visual form based on FM modulation is compared with the visualization of white noise. Although the preference is not as articulated as in the corresponding sound complexity question, a notable amount of users selected the visualization of white noise as being more complex. In the fourth question, two visuals with basic geometries are compared. The distribution is almost even with slight peaks at +2 and +3. A correlation is not evident in this example with the sound complexity. The last question comparing the visual output of an FM sound and white noise has yielded a visible peak at the +3.

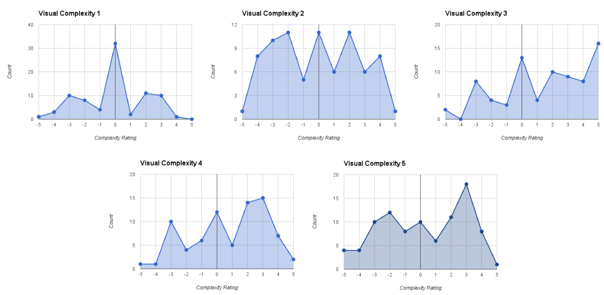

Figure 10: Graphs for visual complexity results

Free-association: Responses to the free association questions can be grouped into the following categories: *affective* (e.g. "wow", "disturbing", "soothing and agitating at the same time"); *perceptual* ("fluid", "cyclic", "irregular"); *abstract/conceptual* ("disorder", "rationalism", "dichotomy"); *representational* ("monstrous", "robot", "flight of a bee or a mosquito"); and *meta-descriptors* ("granular", "pulsations following a low-mid sinusoidal", "this example looks like an artistic visualisation of music", "it draws more complicated and circular shapes when the frequency gets higher"). A small number of participants responded with onomatopoeic descriptors. We have observed the perceptual descriptor category to be the most dominant one across all responses, implying a more abstract interpretation of the material.

6. FUTURE WORK & CONCLUSIONS

We plan to extend *PORTAL* performances in several directions. In terms of hardware, introducing additional laser projectors into the performance can help increase the number of concurrent audiovisual layers. With additional projectors, multiple audio tracks will allow the exploration of figure and ground relationships within both the audio and the visual domains. To achieve three dimensionality in the visual output, we plan to utilize a haze machine, similar to Fox's *Laser Show*. A homogeneous fog generated by these machines makes the laser beam create dynamic imagery suspended in air. Other semi-transparent screening solutions (e.g. tulle curtains, semi-translucent acrylic glass panels, metal meshes) can be used to create layered projections.

Our survey results show that the audience can correlate sounds to their oscillographic output to a certain extent. Particularly, motions in the visual domain are accurately mapped to panoramic and dynamic changes in sound. Furthermore, changes in both sound and visuals based on the same parametric variations are accurately associated on a scale of complexity. The participants were also largely able to map the temporal characteristics of the beating phenomenon across the auditory and visual domains. The audio and visual forms used in our performances appear to incite mental associations that focus on abstract and perceptual qualities rather than those that are representational.

In this paper, we described our audiovisual laser performance project. The hardware implementation described here, and our software, which is available online, can be used by other artists who are interested in exploring audio to visual translations through oscillographic imaging and laser projection. Furthermore, we explored the audience perception our performance practice with an online interactive survey. The results of this study offer interesting insights into the audience perception of audiovisual laser performances in terms of its salient and overlapping features across the auditory and the visual domains. These findings will inform our future performances with the *PORTAL* system.

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