Menagerie: exploring the audio-visual rhythms of violence through data, gun triggers, and swarms

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ABSTRACT

Inspired by the collective behaviors associated with biological swarms, *Menagerie* is a kinetic-sound sculpture that mechanically activates the deconstructed automatic rifle gun trigger as an autonomous sound object to evoke the repetitive nature of gun-related violence. Using statistics taken from the occurrence of firearm-related deaths from each U.S. state, fifty custom-fabricated gun triggers are subject to a specific self-organizing and behavioral algorithm where they align, synchronize, and devolve to reveal the emergent polyrhythms inherent in American patterns of violence. The empty gesture of the unloaded, cold-clicking trigger is emblematic of the listlessness of political action and redress. In this piece, this sound is used as a medium through which the trigger swarm aggregates sonic mass to expose and sonify the timbral density of gun-related violence. This paper presents an overview of the compositional process involved in the design and fabrication of the AR triggers, the programming and control of the self-organizing triggering algorithm, and the aesthetic ramifications of composing for the trigger as a cultural object.

1. INTRODUCTION

By evoking the biological swarm, *Menagerie* [1] aims to reveal the audio-visual patterns that emerge from the statistics associated with gun violence. As such, it ties together research from swarm theory, sonification, and audio-visual synchronization to approximate the collective behavior that arises from the micro-interactions between populations of individual agents. By interrogating the cultural anxieties surrounding firearm ownership, this installation points to a future in which technology, automatization, and a persistent military-industrial complex have created the ideal habitat from which these mechanisms of violence can reproduce, proliferate, and swarm.

Swarm theory can be meaningfully applied to musical contexts insofar as it shows emergent, collective behaviors that can arise in response to simple rule-based systems at the local level. The dynamics underpinning self-organization have been an area of interest for a number of

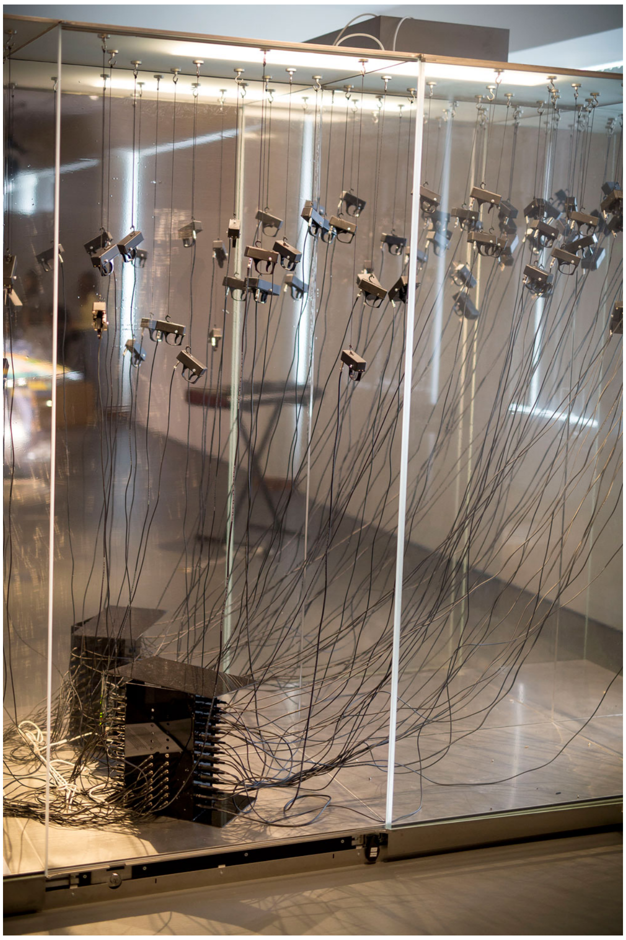

Figure 1. Menagerie at the Danish National Museum of Music (Copenhagen, DK)

research fields related to music including biomusicology, rhythmic entrainment, and music cognition [1, 2]. In the field of applied physics, O'Keefe et al developed a syncing and swarming algorithm that combines both traditional flocking algorithms within a coupled-oscillator network, a model that has particular relevance to the aesthetics goals inherent of this project [3]. Starting in the mid 20th century, several composers began experimenting with compositional techniques that seemed to mimic the timbral mass evoked by the visceral swarm [4]. György Ligeti and Iannis Xenakis in particular are both often credited with developing the "sound mass" aesthetic through the application of "micropolyphony" where dense, atmospheric textures arise from interwoven lines of rhythms, melodies, or tim-

[1] see the installation video: https://vimeo.com/393943856

bres presented *en masse* [5–7]. More recently in the field of computer music, research related to sonifying the virtual swarm has been addressed in numerous papers [8–10]. Using different behavioral algorithms (e.g. flocking), researchers have been able to generate sonic textures that emulate the spatial movement and timbre of the swarm as well as use their behavioral output as control signals [11].

As gun violence has taken center stage in public discourse, there is a rich history of contemporary artists using the gun as a visceral, politically-charged art object. The artist Pedro Reyes has capitulated on this idea by repurposing and deconstructing "weapons of war" to create musical ensembles comprised of autonomous mechanical instruments [12]. Similarly commentating of the ubiquity of gun violence, Luke DuBois' piece, "Take a Bullet for the City" (2014) used real-time data related to firearm discharges in New Orleans to pull the trigger of a handgun loaded with blanks into a gallery space [13]. Responding to the proliferation of tangible forms of computing, these pieces also embody and dialogue with Robles and Wiberg's notion of "texture" as "articulating material relations between the physical and the digital" where different interactive components are drawn into a liminal state [14]. The design strategies often employed in these genres challenge traditional evaluative measure that rely on the form-function dialectic by encouraging more flexible, heterogeneous interpretations [15]. One area of public discourse that subtends a multitude of affects, interests, and controversies is the ubiquity of gun ownership in the US where estimates of firearms possession approach nearly 400 million. What kinds of temporal patterns emerge from this data when we translate the frequency of gun-related deaths to a scale suitable for human interpretation? How can we use the sound of the trigger as a kinetic object to synthesize the acoustics of the swarm?

2. DESIGN

Figure 2. Close up of the triggers

This installation attempts to respond to these research questions in the form of an experiential kinetic audio-visual instrument as shown in Figure . Consequently, this paper summarizes the design of the autonomous gun trigger, the control of the self-synchronizing algorithm, and the fabrication of its constituent parts.

2.1 Material Specifications

In order to imitate the mechanical action and sound of the trigger-pull, *Menagerie* uses fifty push-pull solenoids (6V, 1A) housed inside small aluminum enclosures that act as a basic sort of percussive resonator. After reviewing the a number of real-world trigger mechanisms engineered for automatic weapons, I created my own design from scratch in Fusion360 ® using the constraints of the solenoids shape as a guiding factor (see Figure 3). Triggers and faceplates were exported in vector files and then cut from acrylic sheets using a laser cutter. The triggers are affixed to the enclosure on a simple hinge which allows them to rotate about an axis. The solenoids, when pulsed with a power signal, push the upper part of the trigger forward resulting in a pulling-the-trigger motion. A small elastic band attached to the opposite side of the trigger pulls the trigger back into rest position. As the trigger is pulled, the top portion acts as a hammer that strikes the metallic enclosure. The slightly pitched, percussive sound induced by this motion was intended to mimic an unloaded gun trigger being pulled. In order to connect the triggers to the control circuits, all of the input and output cables were audio-cable type: the input to the trigger enclosures were 1/8" type and their outputs were 1/4" type which were connected to a central electronics unit that houses the control and power circuits.

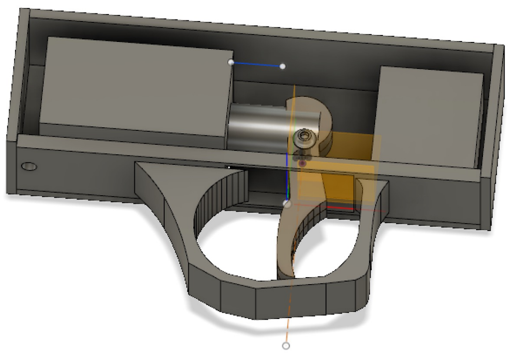

Figure 3. 3D model of the automatic trigger.

2.2 Motor Control and Power Specification

The signals to the individual triggers were controlled by an Arduino Mega using i2C communication with a fully dedicated PWM driver chip (PCA9685 which is an i2C-bus controlled 16 channel LED controller to control 4 H-bridges). The outputs are powered using TB6612 MOSFET drivers that can supply 1.2 A per channel. Each solenoid can be controlled using a 5 bit i2C address that allows for independent control of four motors assigned to each address. If all the solenoids are pulsed at the same time, this could theoretically draw 300 W (in Denmark, where this piece was premiered, that would draw 1.3 A from a 230 V source). In order to sufficiently power the solenoids, thirteen 30 W (@ 6 V) power supplies were used. The duration of the "on" portion of the duty cycle for each pulling-the-trigger event was set to be around 300 ms. The motor control and driver circuits were housed in a centralized electronics enclosure with fifty 1/4" audio outputs and thirteen DC power input jacks.

3. SELF-ORGANIZING RHYTHMS: COMPOSING FOR SYNCHRONY

This installation uses a network of fifty coupled oscillators known as "Kuramoto Oscillators" to generate a wide range of rhythmic states [16]. My previous work has explored to what extent we are able to detect rhythms within quasi-periodic phenomena and applied generative coupled oscillator models to a variety of musical and sonic settings. This paper more explicitly describes a compositional process that exploits the mechanics of this synchronization model to produce the dynamic sonic environments associated with swarm behavior. A brief overview of the physics characterizing these types of dynamical systems will proceed.

3.1 Kuramoto Model

Equation (1) shows the governing equation for a system of limit-cycle oscillators interacting at the group phase level.

$$\dot{\phi_i} = \omega_i + \frac{K_i}{N}\sum_{j=1}^{N} sin(\phi_j - \phi_i) \tag{1}$$

where ϕ_i is the phase of the i_{th} oscillator and $\dot{\phi_i}$ is the derivative of phase with respect to time. ω_i is the intrinsic frequency of the oscillator, i, in a population of N oscillators. K_i is the coupling factor for each oscillator and the $sin(\phi_j - \phi_i)$ term is the phase response function that determines the interaction between each oscillator and the group. In the literature, the range of intrinsic frequencies within the ensemble is typically drawn from a Gaussian distribution, $g(\omega)$ at a center frequency, ω_c.

As K_i is increased, the oscillators with an ω_i closer to ω_c will begin to synchronize to the group by aligning their phases to other oscillators with similar frequencies. As more and more oscillators are recruited, synchrony emerges when $K_i > K_c$ where K_c is the point of critical coupling. Assuming a Gaussian distribution of intrinsic frequencies with a mean of ω_c, Kuramoto was able to show that as the number of oscillators goes to infinity, $K_c = \frac{2}{\pi g(\omega_c)}$.

We can obtain the complex order parameters, R (phase coherence) and ψ (average phase) to solve for the system in the limit as N goes to ∞. This modifies the governing equation to be in terms of a mean-field approximation of the oscillators' phases: each oscillator is no longer beholden to the phase of every other oscillator but is coupled to the ensemble's summed, average phase. This is shown in Equation 2.

$$Re^{j\psi} = \frac{1}{N}\sum_{i=1}^{N} e^{j\psi_i} \tag{2}$$

The phase coherence R is a good indication of the rhythmic congruity of the system at large: when $R = 1$ the phases of each oscillator are completely aligned (at some constant angular velocity) and when $R = 0$, the oscillators are said to be in a desynchronized state where they simply oscillate at their respective ω_i.

As a general sonification model, I used the zero crossing of each oscillators (wrapped) phase to trigger each trigger-pull event once per cycle (when $\phi_{t-1} < \phi_t$ where t is the current iteration). Under the constraints of this mapping, the system behaves like an ensemble of "coupled metronomes".

3.2 Parameterization via Gun Statistics

In order to initialize the intrinsic frequencies (ω_i) for each one of the triggers, I used the rates of gun deaths per 100,000 people across each U.S state taken from the Center for Disease Control and Prevention (CDC) as reflected in the data graphic in Figure 4. Since the data across states is mostly linear, I mapped these onto a trigger frequency range of 0.5 – 3 Hz where each US state is mapped to one of the fifty triggers. Therefore, the U.S. average, 10.87 deaths/100k people, corresponds to a gun triggering frequency of 1.25 Hz. Therefore as predicted by the model mechanics, when $K_{avg} > K_c$, the triggers should align to an isochronous rhythm near this center frequency (this result happens several times throughout the course of the installation).

3.3 Kinetics of Synchrony

In the end, three parameters were updated over time to determine the audio-visual output: the trigger's coupling (K_i), initial frequency (ω_i), and their on-off state (N triggers are "armed" or turned on/off according to an activation trajectory). We can compose for trigger output density and their synchrony by allowing $K_i(t)$ to take on different values over time and by observing how the complex order parameters R and ψ change over time, we can force the system into different synchronous states. The group takes on more complex rhythms (such as the so-called "chimera states") when we allow different triggers to take on different kn_i and for coupling to be repulsive (< 0) instead of attractive [18] which can force the system into unusual polyrhythmic regimes. Similarly, when no coupling is present and N is sufficiently large (> 30), we can no longer detect the individual trigger pulls and the resulting auditory landscape begins to approximate perceptual noise.

My previous psychoacoustics research has investigated the extent to which we are able to entrain to similar types of concurrent auditory events in quasi-periodic auditory sequences [19]. Without sufficient phase alignment, the model produces phenomena that lacks temporal congruity which we found constrains our ability to detect an underlying pulse. Results from this research facilitated the parameterization of the model in order to generate a spectrum of asynchronous, quasi-periodic, and synchronous rhythms. I was motivated by a desire to highlight a number of these rhythmic behaviors by programming the system to step

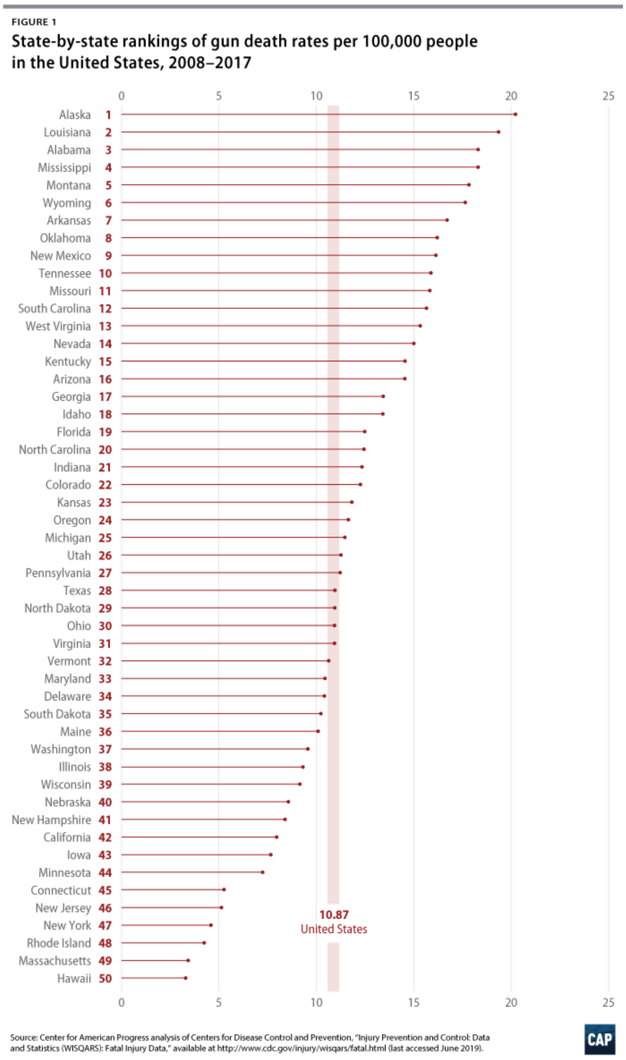

Figure 4. CDC Gun death rate per U.S. state per 100,000 people [17]

through a series of predefined states as seamlessly as possible. Therefore breakpoints for each K_i, w_i, and N were created for each system state, and then linearly interpolated in order to create ramps of increasing, decreasing, or static parameter values per time step. The phase coherence, R, was plotted as a function of time in order to evaluate the rhythmic congruity exhibited by the trigger network.

Initially, these system states were numerically simulated using a model written in Python to produce visual and auditory output to approximate how the the installation would sound. This produced a series of density plots that were subsequently stitched together to create the aggregated composition. Figure 5 shows the first several sections of the piece. Here the y axis is each trigger's output, the blue pulses are pulling-the-trigger events, and the red lines denote each section where the parameters are being modulated over time. As can been seen during the second section, more and more triggers are "armed" and synchronization begins to occur around section three. A larger version of this plot provides an indication of the density of sound events which illustrates when the triggers begin to align, synchronize, or devolve. Figure 6 shows a close up of a short section where various triggers are frequency and phase locking to a center frequency (and synchronizing their trigger pulls).

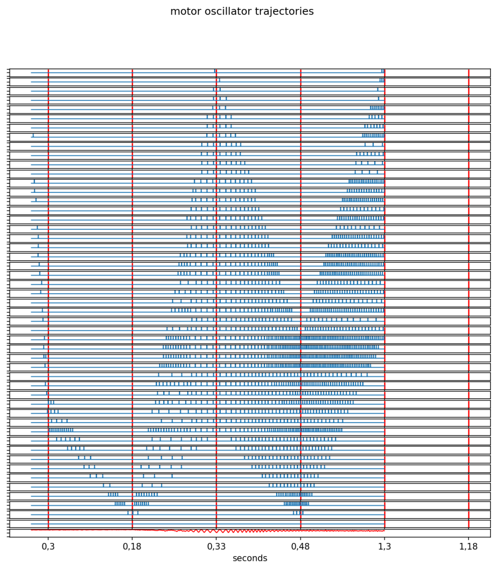

Figure 5. Density Plot for the first minute of the installation
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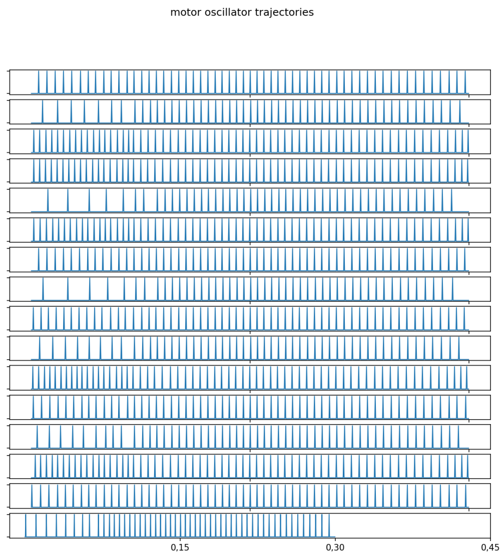

Figure 6. Closeup of 16 triggers becoming entrained to the center frequency (1.25 Hz) over time .

4. CONCLUSIONS

This paper outlined several of the design strategies employed in the production of this large-scale kinetic sound installation which highlighted a number of physical, algorithmic, and aesthetic considerations. The material constraints of composing for a physical swarm brings with it a number of logistical challenges that software-based systems are less likely to encounter. Networks of coupled oscillators have built-in mechanisms for self-synchrony which can be modified over time through relatively simple parameter adjustments to produce an abundance of chaotic, quasi-periodic, or isochronous rhythms. Linking the proliferation of gun related violence with the emergent behavior of self-organizing biological agents, this piece was able to demonstrate how coupled oscillators can be employed as a generative model that approximates the acoustics of swarms.

Acknowledgments

I'd like to thank Professor Stefania Serafin for her tireless support of this project at Aalborg University Copenhagen where I was an artist and researcher in residence during the summer of 2019.

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