ZAP!: Bio-Inspired Large-Scale Multimedia Installation

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ABSTRACT

"ZAP!" is an interactive, biomimetic installation inspired by the electric eel's electrocommunication. The installation translates eel's ability to sense and interact with its environment through electromagnetic fields into a large-scale, multi-sensory experience. This interdisciplinary project combines sound art, architectural sculpture, and interactive design to create an immersive environment. The installation comprises three integrated layers: a physical sculpture embodying the eel's anatomy, a live-generated soundscape reflecting its behavior, and interactive elements that allow spectators to engage with the simulated ecosystem. This paper explores the bio-inspiration behind ZAP!, the design and fabrication of the installation, and the multisensory experience it offers, highlighting the potential of biomimicry to inspire innovative forms of artistic expression.

1. INTRODUCTION AND RELATED WORK

Biomimicry examines natural systems and patterns to derive inspiration for solutions to human challenges. This approach moves beyond simply extracting knowledge from nature, offering a timely opportunity for true learning and integration [1]. While architects have historically drawn on nature for aesthetic inspiration, biomimicry emphasizes functional solutions by adapting underlying biological principles to address design challenges [2]. This research project explores the electric eel (Electrophorus electricus) through a spatial multimedia installation, employing biomimicry in the design of the architectural sculpture to materialize the eel's physical appearance and interaction with its environment. Electric eels are remarkable creatures that inhabit the murky waters of the Amazon and Orinoco river basins and have evolved a unique ability: electrocommunication. They perceive their world through electromagnetic fields, using them not only for navigation and hunting but also for communication with each other [3]. This unique sensory modality is the central inspiration for ZAP!. Specifically, the sculpture adapts the geometrical configuration of the eel's spine, electric organs, and specialized skin cells.

This project exists within a growing field of artistic and research-based explorations at the intersection of animal behavior [4], multimedia art, and biomimicry. This field utilizes immersive spatial components—such as sound, extended reality (XR), and tangible elements—to create mediated experiences that translate natural phenomena for human audiences [5]. ZAP! contributes to this discourse by focusing on the less-explored realm of electrocommunication and translating it into a tangible, interactive, and multisensory artwork.

Within this broader context, several key works offer relevant models. Iannis Xenakis' Polytope of Montreal provides a foundational example of how spatial design can be utilized to create immersive soundscapes [6]. Xenakis' exploration of the geometrical, material, and experiential relationships between light, sound, and architecture, particularly his multi-layered approach juxtaposing distinct sensory modalities, directly informs our design approach in creating a comprehensive, multi-sensory environment where the architectural sculpture, sound, and interaction layers are deeply interwoven. The influence of biomimetic research is also evident in contemporary architecture, where it has led to the development of innovative fabrication techniques and designs. *H.O.R.T.U.S. XL* by Ecologic Studio emplifies this trend, demonstrating how living organisms and their growth patterns can be integrated into algorithmically designed and robotically built architectural structures [7]. This project is relevant to ZAP! as it showcases a contemporary application of biomimicry in creating complex, data-driven architectural forms and highlights the potential of digital fabrication to translate biological principles into tangible, large-scale structures, a methodology central to our sculpture's realization. While *H.O.R.T.U.S. XL* integrates living organisms, ZAP! simulates the eel's behavior and sensory perception, offering a distinct approach to biomimetic design by focusing on the dynamic interplay between the eel and its environment.

In this paper, we will explore the biology of the electric eel's electrocommunication, exploring how these principles informed the design and fabrication of the installation. We will detail the installation's layers, including the architectural sculpture, real-time soundscape, and interactive elements. Furthermore, we will discuss the technical implementation of the project, including the simulation of the eel's behavior and the integration of sound and interactive components. Finally, we will reflect on the audience's experience with the installation and discuss future directions for this bio-inspired artistic exploration.

2. ELECTRIC EEL

Building upon its role as the central inspiration for ZAP!, this section provides a detailed examination of the electric eel's biology, focusing on the mechanisms of its remarkable electrocommunication and associated behaviors.

Electric eels generate electric fields using specialized organs composed of electrocytes. They produce two types of electric organ discharges (EODs): weak and strong. Weak EODs, emitted continuously at around 10 volts, function like an extended sense of touch, allowing the eel to 'see' its surroundings by detecting distortions in the electric field caused by objects or prey [8]. This continuous scanning of the environment inspired the interactive elements of ZAP!, where audience proximity and movement influence the simulated electric field and soundscape. Strong EODs, generated at hundreds of volts, are used for hunting and defense. The eel can unleash these powerful discharges to stun prey or deter predators [9, 10]. The concept of varying electrical output based on situational needs informed the dynamic nature of ZAP!'s sound engine, which changes in response to both the simulated environment and audience interaction.

Electric eels also use their electric fields to communicate with each other, sending instantaneous signals. They detect and interpret these signals using specialized receptors called electroreceptors, located on their skin, and a central processing center in their brain called the Medullary Command Nucleus (MCN). ZAP! attempts to translate this complex communication process into an artistic experience, using sound and light to represent the flow of electrical information within the eel's community. The installation's soundscape, driven by a real-time simulation of the eel's behavior, aims to evoke this intricate network of electrocommunication. By embodying these biological principles, ZAP! offers a unique window into the sensory world of the electric eel.

3. DESIGN AND FABRICATION

The design and fabrication of our project aimes to translate the electric eel's electrocommunication into a tangible and interactive experience for the audience. This involves creating a biomimetic sculpture that embodies the eel's anatomy and evokes its sensory world, coupled with a fabrication process that prioritized sustainability and resourcefulness.

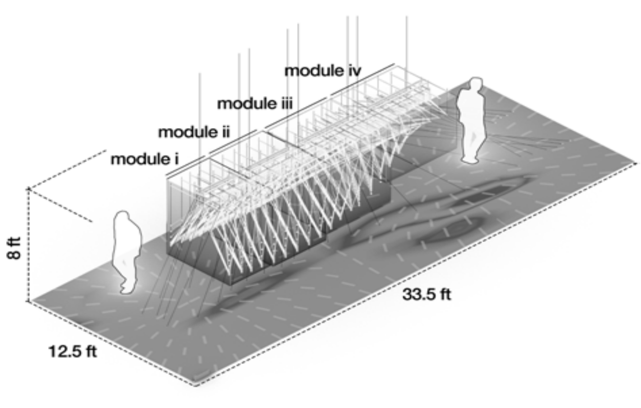

Figure 1. Southwest isometric view of the ceiling suspended installation composed of four modules and the textile floor component.

3.1 Conceptual Design

Rather than striving for a literal representation of the eel, the design prioritizes conveying the essence of its electrocommunication and its interaction with the environment. The central design strategy was to create a tactile and visually compelling representation of the electric eel's electrocommunication. The architectural sculpture serves as a canvas for this exploration, abstracting the eel's anatomical features to create a tangible connection for the audience. The sculpture's form is inspired by the eel's spine and electric organs, representing the source of the electromagnetic fields. Thin fabric strips, woven between the spine and representations of the electric organs, abstractly visualize the flow of electrical signals. The overall design emphasizes transparency and lightness, reflecting the ephemeral nature of electromagnetic fields. A tactile fabric piece on the ground beneath the sculpture further reinforces the presence of the electromagnetic field, featuring a pattern inspired by the field produced between the eel's electric organs.

The installation is designed in four modular pieces, allowing for flexibility in adapting to different exhibition spaces as can be seen in Figure 1. This modularity also provides a dynamic representation of the eel, as the modules can be arranged to suggest different postures and movements as shown in Figure 2.

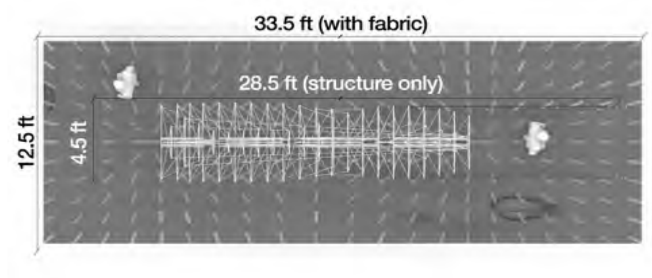

Figure 2. Plan view of the suspended installation component with spectator corridors around and the textile floor component.

3.2 Fabrication Process

The fabrication process prioritizes sustainability by utilizing reclaimed materials. This include various thicknesses of wood, different lengths of PVC pipe, fabric scraps, and PVC joints. The unique characteristics of each reclaimed wood piece, including variations in species, thickness, and moisture content, presented a fabrication challenge. Careful consideration was given to the structural integrity of the sculpture when selecting and arranging these reclaimed components. The wooden elements forming the spine were individually cut, milled, and sanded. Intricate details, such as the pocket milling, are executed using a 5-axis CNC router. The two layers of PVC pipes are also milled and cut to precise dimensions. All components are then spray-painted to achieve a unified aesthetic and reinforce the dematerialized quality associated with electromagnetic fields.

4. IMPLEMENTATION

4.1 Simulating the Electric Eel's Ecosystem

The artificial ecosystem and the behaviors of the eel are implemented using the multimedia programming platform Processing [1]. This simulation, projected onto a wall adjacent to the sculpture as can bee seen in Figure 3, provides a dynamic backdrop for the audience's interaction with the installation. It also serves as a visual score, informing the real-time sound engine. The second layer of the projection is the simulation of the magnetic field, which can be seen in the link provided in section 5.

Our system leverages defined classes like Agent, Food, Obstacle, Environment, and Human to represent various entities within the simulation. The eel's movement is driven by a combination of behaviors like wandering, seeking food when hungry, and reacting to human presence or changes in its surroundings [11]. The simulation models both the dry and wet seasons using the Environment class, changing the visual appearance and behavior of certain elements to reflect seasonal differences. The lights in the room also changes depending on the dry or wet season.

To capture the long-term ecological dynamics of the Amazonian river, the simulation incorporates an internal clock. While the simulation can run indefinitely in real-time, for the purposes of the exhibition, the clock was accelerated to simulate two years within a five-day period. This timeline allowed visitors to experience the full range of seasonal changes and ell's behavior within a reasonable timeframe. Visitors will experience a different environment depending on their visit time, as the simulation and sound engine are interconnected.

4.2 Sound Engine and Compositional Framework

ZAP! utilizes a dynamic and responsive soundscape to immerse the audience in the electric eel's sensory world. The sound engine, built in Max [2], integrates real-time synthesis and interactive elements, drawing inspiration from the eel's electrolocation and communication strategies. The sound environment reacts dynamically to the audience's presence, mirroring the eel's sensitivity to its surroundings. The synthesis techniques of additive, subtractive, and frequency modulation (FM) Synthesis are employed conceptually to represent different aspects of the eel's behavior.

The soundscape is constructed from two interwoven layers. The first layer consists of field recordings captured in the Amazonian River [3] during both the dry and wet seasons. These recordings, played through a 5.0 surround sound system. The selection of these ambient recordings is dynamically linked to the simulated environment. The real-time clock within the simulation triggers different recordings based on the simulated time of day (pre-dawn, dawn, afternoon, morning, night, and evening) and the current season (dry or wet), creating a direct correlation between the simulated eel's environment and the auditory experience. The second layer of the soundscape is generated in real-time, sonifying the simulated eel's behaviors and attributes. Two sets of directional speakers with a subwoofer connected, positioned within the sculpture itself, are dedicated to these synthesized sounds. These sounds are directly driven by the Processing simulation, with the eel's attributes controlling various synthesis parameters. The sound design utilizes three core synthesis techniques, each conceptually mapped to the eel's behavior. Additive synthesis sonifies the eel's subtle and continuous exploration of its environment, represented by its weak EODs. Multiple sine waves of varying frequencies and amplitudes are layered to create a complex, evolving tone, reflecting the eel's constant scanning of its surroundings. Subtractive synthesis represents the eel's powerful hunting strikes, using strong EODs. A rich, harmonically complex waveform is filtered to create sharp, percussive bursts of sound. The filtering allows for dynamic shaping of the sound, creating a sense of focused energy and impact. Finally, FM synthesis sonifies the rapid, paired discharges used in doublet behavior. The specific parameters of these synthesized sounds (pitch, timbre, volume, rhythm, spatial distribution, etc.) are dynamically modulated in real-time based on the eel's actions within the simulation. For example, the frequency and intensity of the 'hunting' sounds might increase as the eel approaches prey, while the rhythmic complexity of the 'doublet' sounds could change depending on the simulated interactions.

As audience members move around the installation, their proximity to the sculpture affects the health and behavior of the electric eel in the simulation. This change in the simulated field, in turn, alters the synthesized sounds, creating a direct link between audience interaction and the sonic representation of the eel's perception.

4.3 Spatial Interaction

The spatial design of ZAP! is centered around the architectural sculpture, which serves as the focal point for audience interaction. The installation encourages exploration and engagement, inviting spectators to experience the eel's world from multiple perspectives. The interaction is designed around three core components: proximity, tactile engagement, and dynamic environmental feedback.

The audience's experience begins with their physical presence in relation to the large-scale sculpture. The sheer size of the sculpture encourages viewers to move around it, exploring its form and the intricate details of its construction. Direct tactile engagement is facilitated through four pressure-sensitive panels embedded within the fabric on the floor beneath the sculpture. These panels, camouflaged to blend with the surrounding environment, are placed at varying distances from the sculpture's spine.

Stepping on the fabric triggers different responses within the simulation. The panel closest to the spine activates the doublet behavior in the simulation. This mode, mimicking a specific electrocommunication behavior in eels, could manifest in a change in the simulated eel's behavior and a corresponding shift in the soundscape. The other three panels, located further from the spine, each reduce the health of the eel when activated creating an auditory representation of the eel's vulnerability. The real-time simulation of the eel's environment, including the changing seasons, adds another layer to the interaction. The simulated seasonal transitions influence both the visual

[1] https://processing.org
[2] https://cycling74.com
[3] https://mindful-audio.com/blog/sound-recording-amazon-rainforest-expedition

Figure 3. (left) multiple spectators and tactile interaction with the sculpture, (middle) layers of the installation; the simulation screen in the background, the architectural sculpture in the center, and spectators, (right) tactile interaction, different light and season.

projection and the multi-channel audio, creating a constantly evolving backdrop for the audience's experience. The changing soundscape, driven by both the simulation and the audience's tactile interactions, reinforces the interconnectedness of the eel, its environment, and the human observers.

The presence of multiple spectators further transforms the exhibition space as can been seen in the video provided under section 5. The interactions and movements of individual audience members combine to create a dynamic and evolving social environment. The collective behavior of the crowd, their proximity to the sculpture, and their engagement with the tactile panels all contribute to the overall atmosphere and the real-time evolution of the soundscape.

5. CONCLUSION AND FUTURE WORK

ZAP! offers a unique exploration of biomimicry in the context of interactive large scale multimedia installation. This work translate electric eel's electrocommunication into a tangible and immersive experience for the audience. By combining architectural sculpture, real-time sound generation, and interactive elements, ZAP! creates a multi-sensory environment. The installation's design, inspired by the eel's anatomy and behavior, serves as a tangible representation. The real-time sound synthesis, driven by both the simulated ecosystem and the audience's interactions, further enhances this experience, creating a responsive environment.

During the installation, we observed that almost all participants interacted with the structure primarily through touch, highlighting the strong appeal of tactile engagement. Future iterations of ZAP! will focus on enhancing this aspect by exploring the potential of a fully conductive structure. This would allow for a more seamless and intuitive interaction, further blurring the lines between the human observer and the simulated eel.

Creating a large-scale installation presents both opportunities and challenges. The scale allows for a deeply immersive experience. However, it also introduces logistical challenges, particularly in terms of transportation and the potential for site-specificity. Future work will address these challenges by refining the modular design and exploring more adaptable fabrication techniques, ensuring that ZAP! can be experienced by a wider audience in different settings. A video documentation of this project can be viewed at: `https://zeynepozcan.github.io/zap`.

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