Interactive Sonification: Aesthetics, Functionality and Performance

Gil Weinberg and Travis Thatcher

ABSTRACT

The authors present a sonification installation that allows a group of players to interact with an auditory display of neural activity. The system is designed to represent electrical spike propagation in a neuron culture through sound propagation in space. Participants can simulate neural spikes by using a set of specially designed controllers, experimenting and sonically investigating the electrical activity of the brain. The article discusses some aesthetic and functional aspects of sonification and describes the authors' approach for group interaction with auditory displays. It concludes with the description of a performance piece for the system and ideas for improvements and future work.

Background and Related Work

With new developments in biological research, scholars are gaining more accurate information about complex systems such as the brain. These developments create a need for effective mechanisms for representation and new approaches for user interaction with such complex datasets. Several visualization techniques have been useful in addressing similar challenges [1,2]. For other applications in fields as diverse as oceanographic buoy readings [3] and stock market trends [4], sonification of data has been found effective, utilizing the auditory system's unique strengths, such as wide spatial cover and aptitude for pattern recognition. Most current sonification applications, however, do not allow for direct hands-on interaction with the information at hand, which hampers their effectiveness in conveying the information. Recent efforts in designing interactive sonification systems focus on guiding users through dataset queries [5,6] but do not support dynamic interaction that can provide both functional and aesthetic sonic experiences. Some sonification systems focus on scientific and utilitarian goals [7–9], while others focus more on aesthetics and music [10,11]. We believe that hands-on dynamic interactions with auditory displays that immerse players musically as well as scientifically in the experience can provide deeper and more intimate sonic familiarity with complex real-world data.

Goals and Motivations

The goal of the project we discuss here, called BrainWaves, is to provide an aesthetically satisfying and scientifically useful representation of complex data sets, derived from electrical activity in neuron cultures. The system is intended to allow a group of players to interact and manipulate spatial propagation of electrical bursts in in-vitro neuron cultures as a means for rich hands-on familiarization with the data. We believe that sonification can be more effective than visualization in such a spatial application because the human auditory system is able to perceive synchronous spatial stimuli from every point within a space, while visual perception is limited to the physical range of sight. The goal of the interaction in BrainWaves is not to browse the dataset but rather to enable users to perceive and explore the data in an immersive manner, providing a direct and intimate connection to the information. By providing players with an interface to trigger neuron spikes in a manner similar to their natural occurrence, we hope to encourage an active learning process about the interconnection and the propagation patterns in the culture. (A spike is a transient variation in voltage or current. Spike propagation is a spatial path created by consecutive spikes.) In addition, a group of players can collaborate in composing a musical piece through interaction with the system, while the encoded information serves as a participant in its own right. In such a performance the neural spikes and propagation clusters are used to influence and prompt players to respond with actions of their own, facilitating the creation of a unique interactive experience. We believe that this novel approach for interaction with sonification can provide artistic and scientific, as well as educational, benefits.

The Data

The data used for the sonification in BrainWaves was recorded and processed by a research group at the Laboratory for Neuro-Engineering at the Georgia Institute of Technology, directed by Steve Potter [12]. As part of an effort to develop new neuroscience technologies for studying learning and memory in vitro, the group grows mammalian brain cells in a culture on multi-electrode arrays, forming an interface between the cultured networks and a computer. One of the main research goals of the group is to "study long term information coding and learning within hybrid systems consisting of cultured cortical neurons and robotic or simulated embodiments" [13]. The data used in BrainWaves was captured from cortical neuron cultures of a mouse cortex, grown over a multi-electrode array arranged in an 8×8 grid [14]. Two different sets of data were used for the project. The first was the raw recorded information from 60 electrodes, measuring the electrical activity in different areas of the culture (four corner electrodes were not used for sensing). This dataset consists of 15 minutes of recorded sensor information from a cell culture that had been exposed to several tetanus stimulations. The second dataset is based on pattern recognition methods used to study the spatial propagation of spikes in the culture. In mature neural cultures, spatially localized bursts become common as groups of neurons generate spikes in clusters, stimulating other clusters to fire. Our sonification system utilizes nine of

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the most commonly occurring burst propagation patterns in the culture, simulating their trajectories as sound propagation in space.

Our Approach

Patterns and pattern recognition are fundamental to both scientific analysis and the arts. In music, rhythmic, melodic and harmonic patterns are some of the most important perceptual building blocks for composers, performers and listeners. Spatialization patterns have also emerged as an important aspect of audio reproduction systems and live musical performance. In BrainWaves, we decided to use spatial auditory patterns to represent the propagation of information in space, aiming to provide both aesthetic and functional benefits. As humans, we use the placement of sound in physical space to gather information about our surrounding environments. In the absence of these basic auditory cues, situational awareness is degraded; the same is true in virtual environments [15]. Adding the dimensions of the physical space to musical compositions or performances enhances the listening experience and gives a composer an additional degree of freedom for musical expression. The spatialization of the sonic environment in BrainWaves plays an important role in supporting the group interaction. It has been shown that the mutual response and real-time interdependency between performing musicians in digital networks can lead to novel musical experiences that cannot be conceived otherwise [16]. Such interdependent user interaction in an immersive and interconnected network can also facilitate engaging learning experiences for participants. As players interact by sending sound waves to each other in a manner that simulates spike propagation in the culture, they become a part of the system, reacting and interacting as do the neurons in the culture. In order to reinforce the functional goals of the system, we also complement the auditory display with a video display (see Fig. 1) that helps represent the information to players and viewers in a multimodal manner. Such multimodal representation has been shown to be effective in similar systems [17].

Implementation

Mappings

In order to provide effective spatial resolution for the representation of a 60-electrode grid, we decided to use an eight-speaker sound system. More speakers might have presented difficulties in conveying the interaction to the audience, also leading to sonic cancellations. Fewer speakers, on the other hand, might not have provided acceptable resolution for adequate spatial representation. In order to represent the 60-electrode data with eight speakers, we had to collate several areas together and experiment with different electrodes and speaker geometries. Our goal was to represent propagation in the culture as accurately as possible in a manner that would fit well with the performance space. We decided to divide the space into eight different zones, as depicted in Fig. 2. Four outer zones extended from the corners of the grid toward the center, and four inner square zones were located around the center in the grid. Such an implementation provided a clear and functional representation of the data. It also served our musical and artistic goals by creating an immersive environment for audience and performers in which interactions were spatially represented through sound and sight. In mapping the data to the speakers, we used each sensor value per time sample to calculate an average of simultaneous values for each zone, testing it against a predetermined threshold. If the value exceeded the threshold, a spike was determined for the appropriate zone. Using statistical data on spike pattern probability given its spatial origination within the culture, we determined which spatial propagation pattern had to be triggered. The sound was then sent through the appropriate speakers, approximating the path of electrical spike propagation.

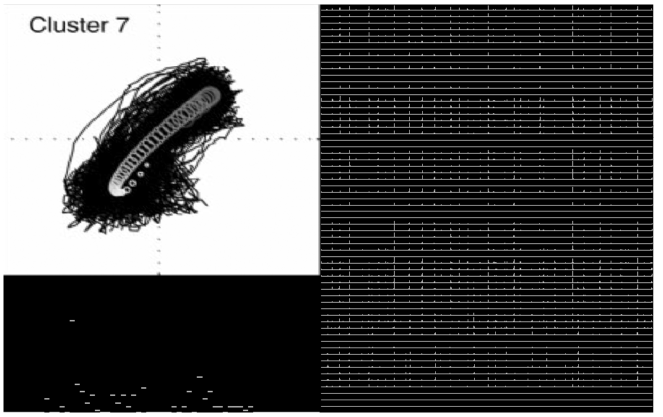
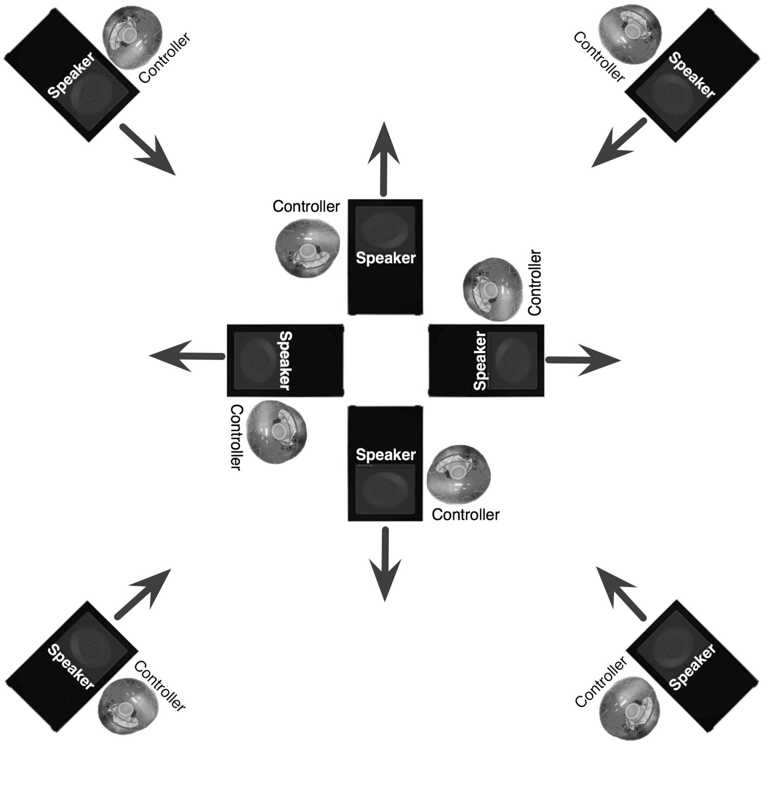


Fig. 1. Real-time visualization of the data as projected to an audience in performance (computer screen shot): (top left) The currently active spike propagation pattern; (right) the sensor history and (bottom left) the real-time data values from 60 electrodes. (© Gil Weinberg)

Fig. 2. Sound projection zones and controller placement in BrainWaves. Audience members can move freely around the space. (© Gil Weinberg)



Audio

The sounds used in the project were chosen to create an interactive environment that fit our musical aesthetics. When idle, the system plays a soft drone using long tones and low-frequency noise textures. When a spike is triggered by the encoded data, harsh, high-frequency sounds are used to represent the propagation patterns. We also allow users to trigger their own spikes using a set of recently developed controllers, as described below in the Interaction section. For these user-triggered spikes, we chose a set of loud, distinctive high-frequency sounds with noisier content. These different sets of sounds were helpful in portraying the interaction to users and the audience, separating the recorded data, the analyzed spike propagation and the user-generated spikes.

Interaction

Eight simple percussive controllers (designed by Clint Cope) were installed next to each speaker, allowing users to simulate spikes and spike propagations by hitting the controllers' surfaces (Fig. 3). Each controller had a piezoelectric sensor to detect hits, an electric circuit to drive LEDs, and two sets of LEDs (at the top and bottom of the controller) designed to provide spatial visual representation of the sound propagation in space. The system was designed for a group of six to eight players (two players at the center of the room could control two stations simultaneously, if desired). It was geared to provide a hands-on experience with the network topology and the high-level structures in the culture. In order to engage players and provide a long-lasting experience, we designed the interaction as a game. Each player could trigger a propagation pattern by hitting his or her respective controller. A wave of sound then propagated from the nearest speaker to other speakers in the space, simulating the neural propagation in the culture. When the pattern ended, the player positioned at that receiving station was prompted to respond with his or her own trigger event, and so on. By allowing players to send waves of sound to a stochastically chosen destination (the propagation cluster was chosen based on its probability in the culture), we added an element of surprise to the system, encouraging players to follow the propagation cluster more closely and to try to surprise their co-players. Free-play interaction schemes were also tried, which often led to shorter, less engaging play sessions.

The Performance

In January 2005 the BrainWaves system was presented at a performance at the Eyedrum Art and Music Gallery in Atlanta, Georgia. The performance began with a brief explanation of the project, followed by a demonstration of the system in idle mode. We then played the recorded neural data accompanied by a visual representation of sensor history, real-time sensor activity and a visual representation of spike propagation each time a spike occurred (see Fig. 1). The system ran the recorded data for several minutes, giving the audience the opportunity to become familiar with the information and its representation. After several minutes, a group of six performers started triggering spikes and propagating sound waves according to the game rules described above. The performance proceeded in this manner, eventually involving all six performers, up to a point where the activity lessened and the system played autonomously again, fading out slowly. When the performance ended, audience members were invited to interact with the system in free play mode (see Fig. 3).

Discussion and Future Work

One of the main challenges we addressed in the process of developing the installation was how to merge our objective scientific goal (providing a clear data representation scheme) with our subjective aesthetic motivation (creating a compelling musical experience) without letting these goals compromise each other. In retrospect, we feel that the trade-off we came up with favored aesthetics and music over science and education. From audience and user reactions, we found that while the environment was intriguing and immersive, the relationships between the data and the sounds, particularly in the interactive sections, were not apparent to everyone. While the projected visualization did help the audience to better understand the activity in the culture, for some players the graphics became the main focus of attention. For the next version of the project, we plan to experiment with less distracting visualization schemes that would complement and augment the auditory artistic experience rather than dominate it. We also plan to improve the auditory display by conducting further experiments with speaker placement and mappings. The sounds we chose for the performance worked well and created the ambience that we aimed for, but the system can benefit from experimentation with other sound sets that are further separated from each other in the frequency domain. This would improve group interaction; at times, players found it difficult to follow the sound propagation. The game interactions were well received and encouraged participants to follow the sounds that they created in space, adding elements of tension and surprise. Some players, however, were prompted to interact far more than others, owing to the fact that many patterns in the data ended in the same few stations. To address this problem we will explore other data sets

Fig. 3. User interaction in BrainWaves. By tapping a percussive controller, visitors can trigger patterns of sound in space, representing electrical spike propagation in the brain. (Photo © Sue Clites)

that may show a larger variety of propagation patterns. We will also investigate and explore other interaction schemes using non-spatial patterns in the data. This may involve implementing new pattern recognition methods, using tools such as neural networks to discover new and potentially meaningful patterns in the culture. Finally, we aim to improve the musical mappings by focusing on elements such as rhythm and harmony, utilizing perceptual concepts such as rhythmic stability and harmonic tension [18,19], which may lead to more interesting structured musical results.

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