Simulating, exploring and optimizing the spatial sound scene of the Sonapticon

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ABSTRACT

The Sonapticon is an audio-visual art installation of illuminated audio-processing speaker sculptures by Tim Otto Roth intertwining between acoustics and neuroscience: as audio neurons, the speakers communicate with each other through open space using tones. Specific tone frequencies are excitatory while other frequencies inhibit the neuron's response. Upon excitation by external sound, some neurons will respond with a specific tone, which other neurons will respond to, yielding a neural-tonal response pattern across the spatial arrangement of the Sonapticons neurons.

We have created a simulation of the Sonapticon's spatiotemporal audiovisual response to external sound. Using the real-time Simulated Field Environment room acoustic simulation software, the transfer paths between all neurons are simulated, taking into account the position and directionality of each neuron. The sound at the two microphones of each neuron is computed and from it the neuron's response. The simulation yields the sound at a listener position, the activation function for each neuron and for the whole Sonapticon. The software simulation allows experiencing the Sonapticon and optimizing its parameters prior to a sound art installation.

Keywords: *sound art; auralization; interaction; Sonapticon; neuronal networks; neuronal feedback.*

Figure 1. First live interaction in 2021 with the 40 audio neurons of the pilot cluster of the Peri-Sonapticon mounted on double steel strings pending from the ceiling. Tones from the Saxophone played by Yérri-Gaspar Hummel excite the Sonapticons neurons, which respond with a specific tone. This acoustic response in turn will excite other neurons depending on excitatory and inhibitory tone input from all neurons, external sound, reverberation and the spatial configuration to result in a pattern of acoustic neuronal firing. For a video impression see: www.pixelsex.org/sonapticon.

1. INTRODUCTION

Neuronal networks drive our brain and in a simplified way also machine learning. Networks are the focus of computational neuroscience, and sometimes also of art and music. "It may not look much like it at first, but this is your brain on music," wrote the British music critique Robert Barry on the occasion of the premiere of the Sonapticon, which was first elaborated for the fixed hemispherical

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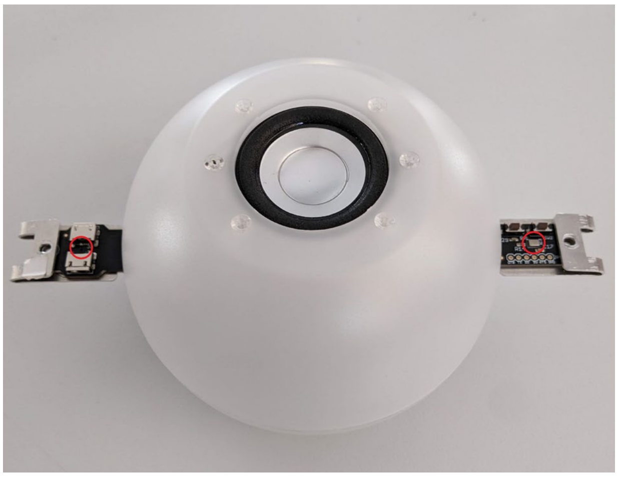


Figure 2. A single Sonapticon audio neuron sculpture housed in two polycarbonate shells (d=12cm). A second loudspeaker chassis is located on the opposite side. Red circles highlight the two microphones of the custom-made electronics.

speaker setting of the Sound Dome at the Centre for Art and Media ZKM Karlsruhe [1]. To achieve more flexibility for including also other locations, Tim Otto Roth's studio designed little audio neuron speaker sculptures, which can be distributed over a whole space. This immersive Peri-Sonapticon can be scaled to create networks from 40 up to 125 audio neurons, which mimic the behavior of their neural counterpart – just slowed down and with audio input and output substituting the electrophysiological wiring (Figure 1). The Sonapticon auralizes and visualizes by integrated LEDs neuronal connectivity that is initiated by external sound input, but then results in sustained responses, cycling through tone patterns, which can be altered by external sound input. It is important to underline that the Sonapticon differs fundamentally from a sonification of pre-recorded simulations of a neuronal network, as the performing network is only formed in the here and now of the specific analog spatial situation. The visitor thus stands in real-time in the midst of a neurobiologically driven network of tones. "The sonic event does not represent anything here. What we hear is the process in the room itself," resumes Tim Otto Roth in an interview with musicologist Rainer Bayreuther [2].

Of course, the spatial configuration and the room transfer functions between neurons and the external sound source are crucial parameters for the response properties. The aim of the present simulation is to predict each neuron's response in response to the other neuron responses, to external sound input and to the room acoustic coupling between neurons. The real-time simulation provides a visualization and auralization such that acoustically interesting parametrizations can be developed in preparation for a site-specific sound art installation, also anticipating the acoustic interaction by the audience or musicians.

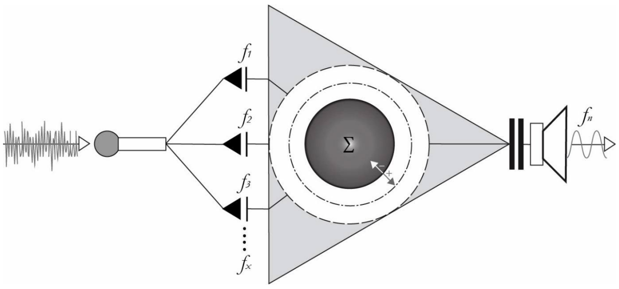


Figure 3. Working principle of the Sonapticon audio neuron: Sound is picked up by a microphone and analyzed using an FFT to identify the amplitude at excitatory and inhibitory frequencies, which will act like axonal input in the subsequent synapse. The synapse is modeled with a leaky integrate-and-fire model. Upon threshold crossing, a tone at a frequency specific to the neuron is played. Image from [3].

2. METHODS

2.1 Sonapticon audio neuron

The Sonapticon's audio neuron translates the behavior of a real neuron to synaptic input into the audio domain (Figures 2 and 3). Sound is picked up by two ICS-43434 microphones (InvenSense, San Jose, CA, USA) and analyzed using an FFT to identify the amplitude at pre-defined excitatory and inhibitory frequencies. These tone inputs act like excitatory and inhibitory axonal inputs in the subsequent synapse. The synapse is modeled with a leaky integrate-and-fire model [4], which was extended for embedding in neural networks [5]. The original neuron's time constants were slowed to enable an acoustic impression of tones and melodies. Upon threshold crossing a tone is generated at a frequency specific to the neuron and played via a MAX98357 PWM class D amplifier (Maxim Integrated Products Inc., San Jose, CA, USA) driving two BF 45 loudspeaker chassis (Visaton, Haan, Germany). All processing is realized on an ESP32 WROOM processor programmed with the Arduino IDE. Currently, an upgrade to the ESP32 S3 processor is in preparation providing with 8 MB 16 times more RAM to refine the frequency tracking. The Sonapticon's audio neuron directionality was measured for the present simulation in an anechoic chamber and is illustrated in Figure 4.

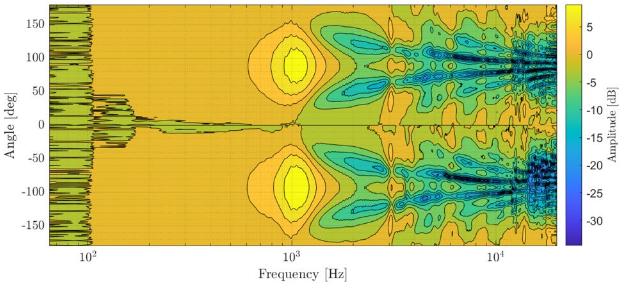


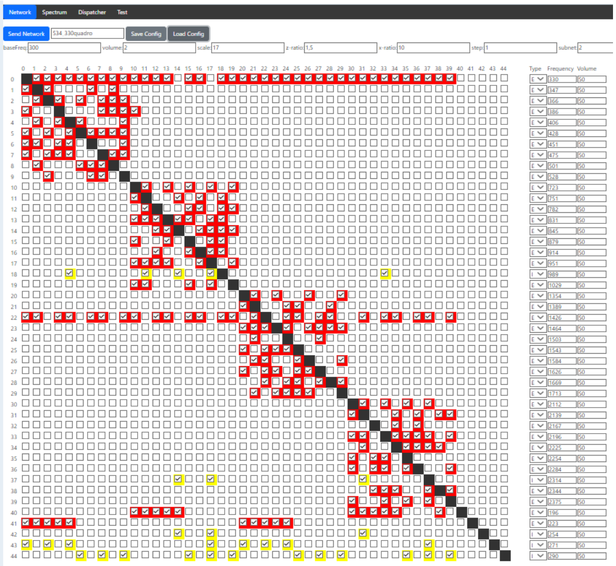
Figure 4. Horizontal directivity of the audio neuron. Isobaric contour spacing is 3 dB. The loudspeakers are facing 0° and 180°.

2.2 real-time Simulated Open Field Environment

The real-time Simulated Open Field Environment (rtSOFE) [6] is a fast, C++coded implementation of the extended image source method for acoustic room simulation [7, 8] and, together with its convolver, can be used for interactive auralization. It is freely available [9]. rtSOFE can efficiently simulate sound reflections off arbitrary geometric surface arrangements to high geometric orders. Complex backtracking, visibility and protrusion tests are done for each created image source. Visible image sources are synthesized into impulse responses taking surface absorption, distance, air absorption, and also source and receiver directivity into account. The present simulation considers the audio neurons' directivity (Figure 4) and models an omnidirectional receiver, though a binaural receiver could also be used.

2.3 Peri-Sonapticon simulation

The simulation of the Peri-Sonapticon audio-neural network is programmed in Matlab and takes external input to stimulate the neurons, computes the sound transfer between the neurons and the audio neuron responses, and the sound at a listener site. In doing so, it simulates the relevant room acoustic paths between all neurons and from the external sound source to all neurons and from the neurons to the receiver. Acoustic paths on frequencies not considered by a particular receiving neuron could be skipped. The room acoustic transfer paths are pre-computed for the current room acoustic configuration and audio neuron locations with rtSOFE at the program start since the audio neurons do not move. Also, because each neuron responds with a pre-defined tone, the room impulse response can be pre-convolved with the tone. At the run- time of the simulation, the acoustic input of each neuron is summed from all other active neurons and the real-time audio input from the soundcard in sample blocks equal to the size of the neuron's FFT. These audio inputs are handed to the neuron simulation based on the Python code the Arduino code for the microprocessors is derived from. This Python code was modified to interface with the simulation code. The code returns if the neuron was firing in the time block, which triggers the sound output of this neuron in the simulation. The listener is treated like a neuron in space and receives the summed sound output of all neurons plus the external sound for real-time listening. At the same time, the FFT's output, i.e., the neuron's excitatory and inhibitory input, and the neuron's potential are plotted and the image of the neurons are color-animated according to the color scheme of the Sonapticon's illumination. The GUI to set all parameters is displayed in Figure 5.



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baseFreq: 300
volume: 2
scale: 17
z-ratio: 1,5
x-ratio: 10
step: 1
subnet: 2

Figure 5. Browser-based control GUI to set connections and excitatory and inhibitory frequencies of all neurons. The current matrix shows a network configuration with four weakly interconnected subnetworks.

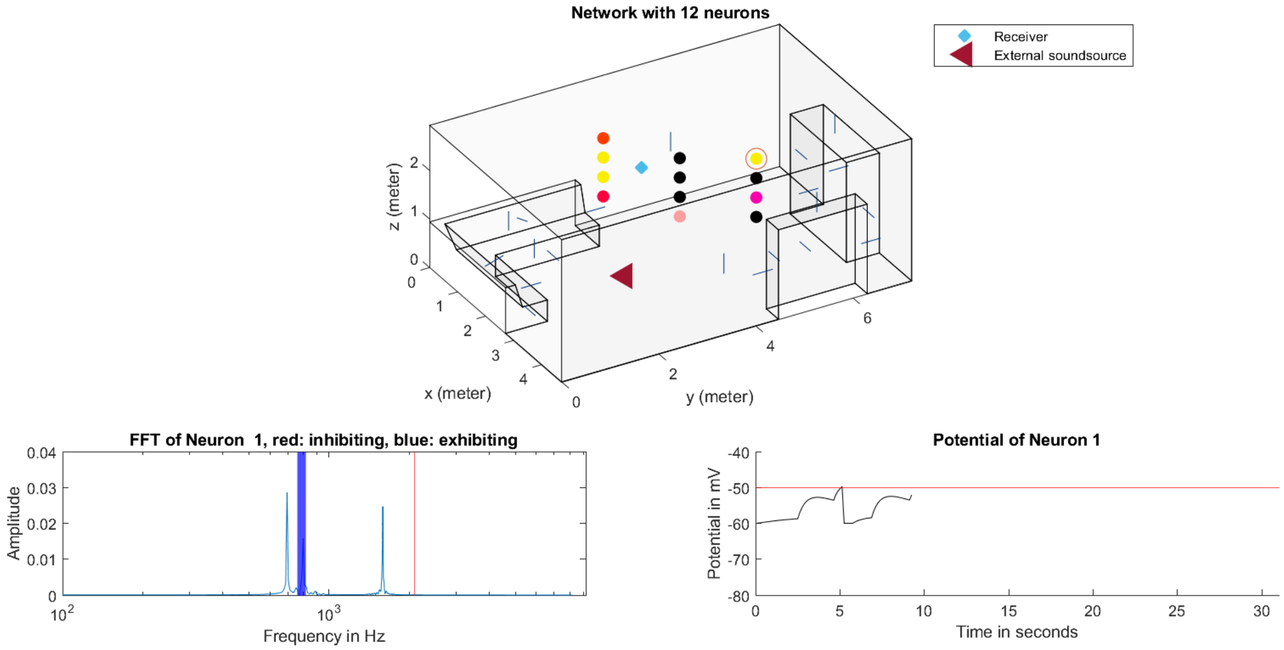

Figure 6. Simulation of the Sonapticon behavior in a virtual room. Top: Position of audio neurons, audio source and receiver in the simulated room. Bottom left: FFT output of neuron 1 indicating the amplitude of excitatory and inhibitory frequencies. At this moment, a spike from another neuron acoustically connected with neuron 1 is detected (thick blue line), leading to a rise in the potential of neuron 1. Bottom right: Membrane potential of neuron 1 as a function of time. The potential crosses the threshold at around 5 sec, leading to a firing of neuron 1.

3. RESULTS

Figure 6 shows the simulation output of one of twelve Peri-Sonapticon neurons placed in the virtual acoustic space of our seminar room. The receiver is close to the window-side chain of neurons; the source is further away, beyond the critical distance in that room. The simulation plots the FFT amplitudes dynamically in the lower left part – the depicted snapshot at the end of the simulation indicates the excitatory five frequencies. The lower right sub-figure shows the time course of the neuron's potential and the moment when it crossed the firing threshold. There will be multiple moments of firing, i.e., tone creation, later in the present sequence, indicating the cyclic nature of activation and deactivation of the neuron. The Sonapticon's neurons play a sequence of tones that converges to an "Eigenmelody" depending on the initial sound input and the transfer paths between neurons in the absence of subsequent external sound input.

Since the simulation can be freely configured in the parameters of all neurons of the Peri-Sonapticon as well as the acoustic room conditions they are placed in, the actual response behavior of a specific Sonapticon parametrization with its spatial arrangement in an exhibition space can be predicted (c.f. Figure 1). This permits offline-tuning and evaluation of parameters to find conditions – first of all, a correspondent network connectivity – in which the neurons can excite each other such that "melody" like microtonal sequences of sufficient length are generated or a self-synchronizing behavior of synchronously firing neurons is provoked. Above all, the effect of changing external triggers can be tested to avoid infinite loops. The effect of spatial parameters can be explored not only by placing neurons in different locations but particularly by changing the neuron mapping of the same network, leading to different connectivity due to acoustic interferences. The simulation is a great tool extension for the artist and composer Tim Otto Roth: "The Sonapticon is a new way of composing music as you assign frequencies to the audio neurons and you design networks and subnetworks, which sound completely different in each new spatial setting. Here, the simulation environment puts the composition process to a new level."

4. CONCLUSIONS

The present simulation of the Peri-Sonapticon combines room acoustic modeling, neural modeling, real-time programming and auralization to simulate and predict the audible side of the artistic outcome of the sound art installation. The simulation takes into account each neuron's parameters for excitatory and inhibitory tones, simulates the acoustic transfer between neurons in real time and auralizes neuron response of the whole Peri-Sonapticon at a chosen listener position in a room. The simulation gives the user an impression of the art installation and a tool to predict the audio network's response in a specific exhibition space. Thus, it can be used to prepare an upcoming exhibition or concert by finding optimal parameters for each audio neuron.

5. ACKNOWLEDGMENTS

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