SONAPTICON -SPACE AS AN ACOUSTIC NEURONAL NETWORK

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Tim Otto Roth
Imachination Projects,
Oppenau/ Cologne, Germany
tor@imachination.net

RÉSUMÉ

The Sonapction connects acoustics and neuroscience with space changing the Sound Dome with its 43 loudspeakers at the Center for Arts and Media ZKM Karlsruhe literally into a musical mindstorm. [1] The core of the system are the so called audio neurons communicating not with electric currents but with sound waves. This unique translation of neuronal systems' electrical communication into acoustic communication is combined with the deceleration of biological neuronal processes that take place on the timescale of milliseconds. In this way, in the Sonapticon neuronal communication mechanisms become both a sensual and a comprehensible experience. At the concert like Premiere in the context of the ZKM's IMATRONIC festival and the symposium Neuroaesthetics [2] in November 2012 three solo piccolo players revealed by a simple combinatoric play [3] the different facets of the Sonapticon, to be it a microtonal sound wash or a pseudo repetitive pattern in the inaudible sound spectrum of ultra sound.

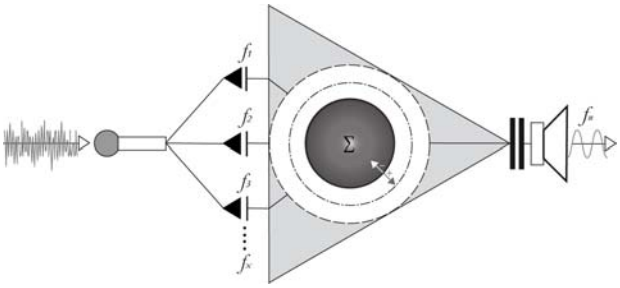

Figure 1. Scheme of an audio neurone.

1. INTRODUCTION – ACOUSTIC FEEDBACK

Biological neurons are interconnected by organic wires and communicate by short electric impulses, so-called 'spikes'. In fig.1 you see a simple scheme of how a neuron works: The incoming impulses are summed up and change the membrane potential of a neuron. There are two different types of incoming spikes: if the spike increases the membrane potential, the sending neuron is called excitatory, if it decreases the potential, the sender is called inhibitory.

In the absence of external input, the membrane potential decays to a resting potential which is marked by the inner dashed ring. A neuron sends out an electric impulse, it 'fires', when the incoming impulses from other neurons force the potential over a certain threshold, here indicated by the outer dashed ring. After having fired the neuron is not excitable for a certain period of time and the potential goes back to the resting potential.

Most people do know feedback in acoustic systems as a cascading effect of a microcophone in combination with a loudspeaker. The Sonapticon uses a similar but different scheme. The basic units of the Sonapticon are audio neurons interconnected not by wires but by sound transmitted in space. An audio neuron registers impulses (*spikes*) from its acoustic environment by a microphone and fires its own impulse by a loudspeaker (fig.1). The clue of that system is that every neuron gets assigned a sine tone with an individual frequency.

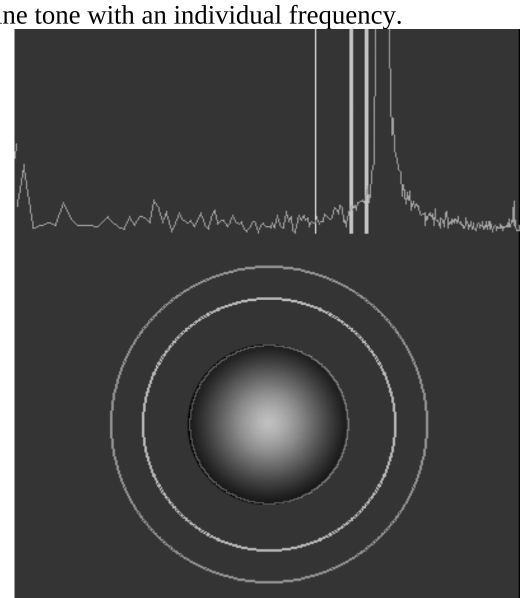

Figure 2: Visualization of the Python based audio-neuron showing the frequency tracking (top), the current membrane potential (circle in the middle) and the history plot of the membrane potential (bottom).

Looking to a sound spectrum you see that most sounds do consist of a broad band of frequencies. But sine tones oscillating at a single frequency show up characteristic peaks in a spectrum (see top of fig. 2). This is how you can simply connect the audio neurons: Every audio neuron registers a specific set of frequencies assigned to other neurons. These frequencies are marked as lines in two colours in the spectrum. If an audio neuron registers a significant steep peak at one of these lines it interprets this as impulse of a connected neuron and the line flashes. Depending on the colour assigned to a line an impulse has an excitatory or inhibitory effect.

2. DECELERATION OF BIOLOGICAL PROCESSES

Unlike in *in vivo* neural tissue, where neuronal interactions occur on the timescale of milliseconds, the Sonapticon allows to decelerate all biological processes by the factor 10-200. This generates an environment where spectators can identify and understand intuitively the causal relationship between integration and initiation of spikes on a single neuron level. Thereby, the Sonapticon creates an unprecedented sensual experience of the basic computational principles that underlie all mental processes, be it the initiation of movement, the creation of simple thoughts, or even the emergence of consciousness.

This simple interaction scheme is the basis of all nervous activity. It is still an enigma how these interactions form something like a simple thought in our brain. With latest microscopic techniques you can observe *in vivo* in small probes of neuronal tissues how firing neurons self-organize and create synchronized activity patterns clip. Unlike in *in vivo* neural tissue, where neuronal interactions occur on the timescale of milliseconds, the *in silico* technique of the Sonapticon allows to decelerate all biological processes. This generates an environment where spectators can identify and understand intuitively the causal relationship between integration and initiation of spikes on a single neuron level.

Consequently the Sonapticon is a system of decelerated synthetic neurons which allows a real time interaction with neuronal dynamics and control of the biological parameters. The Sonapticon combines two basic components:

- digital *in silico* methods, with latest mathematical models of biological neurons (e. g. the conductivity based model by Alain Destexhe) [4]

and

- an empirical environment (the Sound Dome) using acoustics as an analogue space of experimentation and interaction. Here delay effects come into play due to the propagation speed of sound resulting in dynamics which differ essentially from cable wired systems.

Principally every computing device with a microphone and loudspeaker can function as an audio neuron to be it a laptop, a tablet computer or a smart phone. In August 2012 a first performance did take place at the Bernstein Centre for Computational Neuroscience on the Campus of the Charité in Berlin. The visitors installed a little python based software (see screenshot fig. 2) to be it for PC or Mac and changed their laptops with small external speakers into acoustic neurons. Step by step a network of twenty acoustic neurons was built up, exploring the changing dynamics by adding further neurons.

Above all the Sonapticon invites to interact with the system in all different forms. An instrument like the singing saw producing clear sine peaks resulted to be a perfect device to explore the system's resonances.

3. THE SONAPTICON AT THE ZKM'S SOUND DOME

Thanks to the invitation by the Institute of Music and Acoustics at the Center for Art and Media, ZKM Karlsruhe we – the author and the neuro-mathematician Benjamin Staude – could explore together the Sonapticon as guest composers from 2010-12 in a very sophisticated environment. In collaboration with the sound engineer Holger Stenschke from ZKM we were changing the Sound Dome into an acoustic neuronal network. The Sound Dome consists of 43 loudspeakers building an impressing hemisphere of 15 meters in diameter. The loudspeakers get joined via microphones. Intuitive understanding of the acoustic feedback through sine tones in the Sound Dome space is complemented visually through LED lights mounted on the speakers flashing up in a blue or yellow colour in case the neuron is firing. Above all a video projection on the floor shows a visualization of all the active neurons with their changing membrane potentials.

Figure 3: Impression from the premiere with three piccolo players standing around the floor projection and flashing loudspeakers in the background.

In the ZKM's Sound Dome the audio analysis uses a frame work based on MaxMsp programmed by Holger Stenschke. The adaptation of the neuron model and the composition frame work was realized in Python by Benjamin Staude. For the visualization Tim Otto Roth used Gem in combination with Puredata.

4. SPACE

First of all the Sonapticon creates in the Sound Dome a completely new experience emerging the visitor into a surrounding acoustic atmosphere: You feel to stand in the middle of an organic process of self organizing tones.

Above all the use of sine tones assigned to specific loudspeaker in the space creates a particular effect. If you are walking around in the installation the sine tone patterns recompose differently in the visitors ears depending on the locally dominant tones. If the system runs very fast you even get the effect of standing waves changing even if you slightly turn the head.

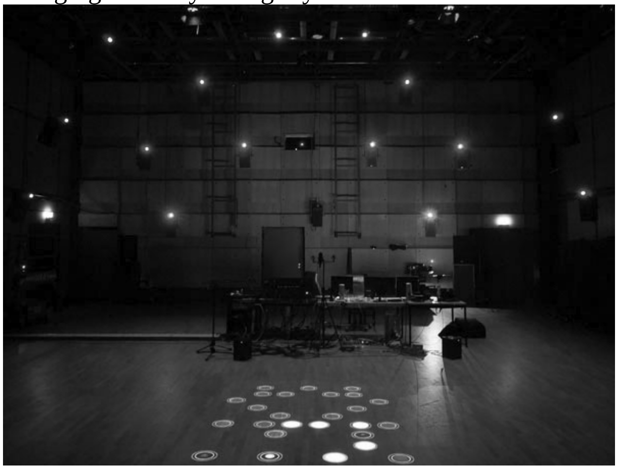

Figure 3: Impression from the audio visual spatial setting in the Sound Dome (Klangdom) at the ZKM Karlsruhe.

Finally this controlled environment allows to explore systematically the characteristics of the Sonapticon. For instance with regards to the size of the Sound Dome and the speed how sound waves propagate in space delay effects come into play which appear also in neuronal tissues: So here it makes a difference where and when a sound is played in the environment – an invitation for musicians to play with the environment.

5. A NEW INSTRUMENT

Thus, we transformed with the Sonapticon the Sound Dome into a new instrument for which we have developed a special method of composing in and with the Sound Dome space: choosing scales up to the eighth tone range, giving tones a location by assigning frequencies to an audio neuron, setting the connections between the audio neurons and finally varying the tempi by playing with the system's update rate.

The piece at the concert premiere comprised eight movements starting with a single neuron. Step by step the number of neurons the three piccolo players interacted with was increased. Above all the composition used different tonalities as a Western chromatic, an Indian Shruti or a microtonal eighth tone scale. In the last movements the frequencies were transposed subsequently by perfect fifths ending up in a finale with inaudible ultra sound.

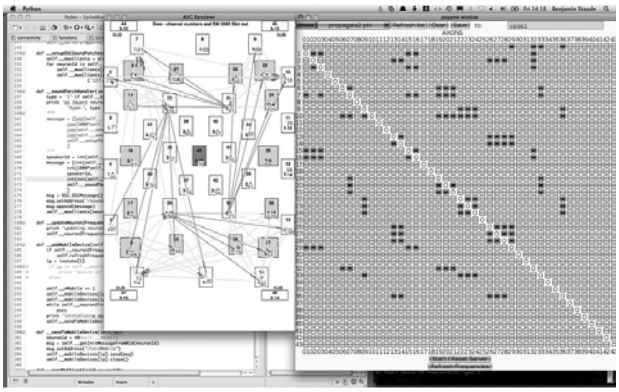

Figure 4. Compostion matrix with connection map at the right and the resulting network at the left.

Finally the models themselves are a playfield for composition. Parameters can be changed globally, but also the characteristics of individual neurons can be varied. Modifying the ratio of neurons and interneurons has a significant effect. Until now this was studied only rudimentary, so it is a future task for the Sonapticon to explore also with different models acoustically the phenomenon of synaptic plasticity.

6. REFERENCES

[1] An extended documentation of the project including two video introductions is provided by the project page: http://www.pixelsex.org/sonapticon.

[2] Record of Tim Otto Roth's and Benjamin Staude's talk on the Neuroaesthetics symposium at ZKM Karlsruhe: https://itunes.apple.com/de/itunes-u/neuroaesthetics-symposium/id601309561?mt=10 .

[3] Only one tone is played by each player in a certain sequence, so together the three soloists play all possible tone combinations. This time based combinatory play is inspired by Tom Johnson's counting pieces. See: http://www.editions75.com .

[4] Destexhe, Alain: Self-sustained asynchronous irregular states and Up–Down states in thalamic, cortical and thalamocortical networks of nonlinear integrate-and-fire neurons, in: Journal of Computational Neuroscience 27 (Dec 2009) Nr. 3, p. 493-506. Destexhe's model has been adapted by adding a refractory period.

[5] Barry, Robert: Artist collaborates with neuroscientist to build 'audio-neurons', interview on wired.co.uk (10 December 2012), http://www.wired.co.uk/news/archive/2012-12/10/tim-otto-roth .