Modeling Auditory Pathway: A neuromorphic VLSI system with Integrate & Fire Neurons and on-chip learning Synapses

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Abstract. This work handles a neuromorphic VLSI system used for acoustical processing. The localization and separation of sound sources out of data overcrowded environment models the auditory pathway. The azimuthal localization is based on an analysis of interaural time delay. Sounds are selected by a knowledge guided principle of recent appearance and importance to the system. The system was designed to provide a silicon solution for the interaction of acoustical with other sensoric information at the autonomous robot MILVA.

The system is built by four functional stages. First unit, the peripheral processing consists of Cochlear mechanics and Inner Hair Cells (IHC). It exist twice and models receptive channels of inner ear. The functionality of the Cochlear mechanics has been simulated parallel on a CNAPS processor architecture. Currently analog filters for 32 channels are being developed. For each of the frequency channels the continuous signals are coded into time discrete binary pulses. This coding procedure is performed in the IHC. All of the acoustical information coded into the timing of spikes will be processed this way throughout a neural network.

The second stage secures the source localization of timing pathway. Feeding the IHC output through two counter-propagating delay lines the difference between left and right ear can be destined. Subsequent two neuron layers act as coincidence detectors and summation over the frequencies, respectively. The spatial resolution depends on the base distance of microphones as well as the clock rate. New appearing or moving sound sources are selected by specific topology of the following stage, a phase focusation unit. An activity dependent self inhibitory neuron is assigned to each focus cell. Receiving the same input, it is suppressing long term firing of the subsequent unit. The second condition for sound selection is an importance to the system. To develop some knowledge by learning typical sounds and to exclude them from the attentional procedure is the task of the Auditory Cortex, the last stage. A fully connected one layer neural structure employing Hebbian learning rule performs as dynamic memory for sound pattern. After subtraction repeating signals the output of this stage is directly coupled to the focusation layer. This way the excitatory firing from Cortex will increase the firing probability of the focus unit.

For the realization of the system except the Cochlear mechanics we have chosen a CMOS technology. The hardware implementation is based on uniform analog Integrate & Fire cells (IF). The advantage of using a basic cell type, is the preservation of hardware variability and the realization of different neural structures and functions. The IF model circuit includes a spatio-temporal sum of synaptic inputs (current pulse on Soma Potential Capacitor), After-Hyperpolarisation during a refractory period (lifting the threshold), firing history (used in synapses for the learning procedure). In every learning synapse a 5pF capacitor is used for weight storaging. Therefore the major problem is the bad long term storage of weight values. A necessary refresh unit have been designed for discharge compensation. The principle is based on continuos comparison between the capacitor voltage and increasing ramp reference.
An example of the learning synapse and the IF neuron have been implemented in a 2.4μm CMOS technology and are being measured presently. For the verification of sound localization a next implementation of a small network including IHC, IF neurons and non-learning synapse is under way.