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Report

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System of aVLSI Spiking Neurons and Dynamic Synapses for Real-Time Cortical Modeling

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We developed a multi-neuron chip which comprises two networks of spiking neurons and dynamic synapses. This chip is a building block for a multi-chip spike-based system that can be used to explore spike-based models which use dynamic synapses. We mapped a direction-selective model onto the chip. Results from the chip are qualitatively similar to those obtained from the computer-simulated model.

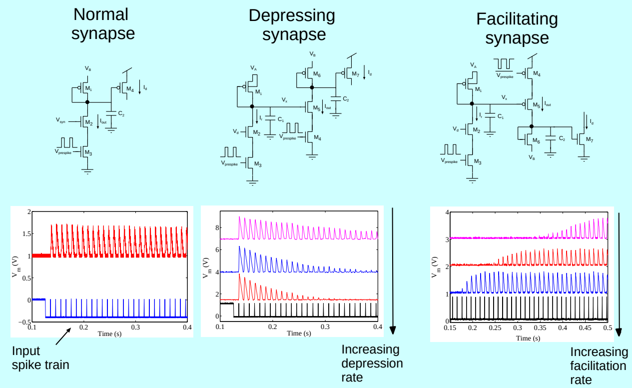
Dynamic synapses

Dynamic synapses provide short-term plasticity for dynamic gain control in many cortical areas. They are an intricate part of numerous cortical models [1][2]. The dynamics of these synapses provide short-time depression or facilitation. Fig 1 shows the silicon synaptic circuits and EPSPs when stimulated by a presynaptic regular input spike train of 50 Hz (lowest curve) through three synapses with different dynamics.

Chip architecture

The multi-neuron chip (layout in Fig 2) has two layers of 64 neurons. These neurons can be stimulated externally through an address-event representation (AER) protocol [3] by an excitatory synapse, a depressing synapse [4], and an inhibitory synapse. Each layer has 63 excitatory neurons and 1 global inhibitory neuron. The excitatory neurons excite the global interneuron which in return, inhibits the excitatory neurons. Connections between the excitatory neurons can be configured using the AER protocol. The neurons in the two networks are coupled together through facilitating synapses to resemble the functional connectivity of L4 and L6 neurons in V1.

FIG. 1



Direction-selective silicon model

Chance's direction-selective model [5] (Fig 3) uses the properties of dynamic synapses to explain the direction-selective response of V1 neurons. We implemented this model on the multi-neuron chip using inputs recorded from a cat LGN neuron (courtesy of K. Martin) in response to a drifting sinusoidal grating of different temporal frequencies. The responses of this silicon direction-selective model when shown a stimulus in the preferred direction (upper curve) and null direction (lower curve) are shown in Fig 3.

FIG. 2

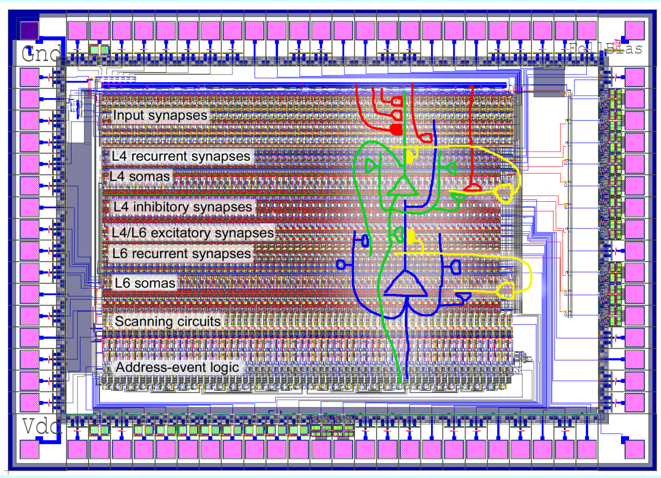
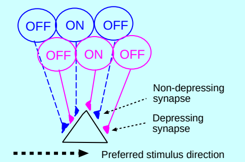
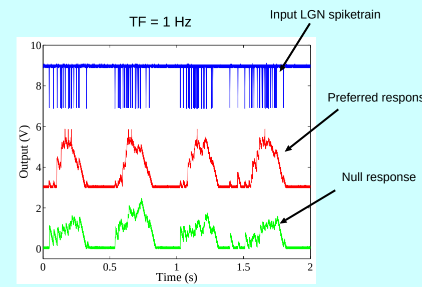


FIG. 3



Two spatially displaced sets of LGN neurons excite the V1 neuron through non-depressing and depressing synapses respectively. The depressing synapses phase-advance the LGN signal so the membrane potential of the neuron is close to threshold when the subsequent LGN input excites the neuron through the non-depressing synapses.



Conclusions

1) The multi-neuron chip with dynamic synapses produces behavior for the direction-selective model which is qualitatively similar that of the computer-simulated model.
2) The similarity of responses indicates that this multi-neuron chip can be used to explore complex spike-based processing models (for example, direction-selective and orientation-selective models) in *real time*.
3) Network properties which incorporate the interaction between the two layers of neurons are being studied.

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