Biomorphic Analog Neural Circuitry

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Silicon neurons [1]-[4] model biological complexity to different degrees, trading realism for simplicity. This work provides a set of biomorphic mixed-mode circuits designed to efficiently implement the spiking neuron model specified in [5], a modification of the Eckhorn model[6].

Fig. 1 shows the circuit diagram of the spiking neuron soma. The clocked circuit pumps charge through a subthreshold biased transistor M1 onto the gate capacitance of transistor M2 that represents the neuron membrane. The current source produced by the clock and M1 is intentionally made fairly poor (low output impedance) in order to produce a non-linear membrane potential buildup. When the membrane potential rises enough to pull M3 out of its linear region, the voltage at the swing node rapidly falls as M2 pulls the node down towards ground. The low voltage on the swing node then triggers the inverter formed by M4 and M5 to go high and this voltage is digitally buffered to the output. The clocked switch formed by M7 latches the voltage output on the non-charging cycle of the current pump at M1. M8 and M9 are sized such that this inverter triggers for a relatively high DC voltage so as to insure good spike amplitude before the discharge transistor M6 is activated. When M6 is switched on, all charge at the membrane is drained to ground or alternatively to whatever resting potential is connected at the source of M6. When the membrane potential falls, M2 shuts down and the swing node is pulled high again as M3 returns to its linear region. This change in the swing node returns the output to low, ending the spike and switching off the discharge transistor at M6. Simulation results show the membrane potential builds up incrementally in small steps with a decreasing slope until it passes threshold, at which point a digital level spike is generated at the output. At the next non-charging cycle (when the clock is low) the output spike is latched and used to discharge the membrane, pulling the output low to finish the spike.

Fig. 2 shows an excitatory synapto-dendritic input circuit that connects the Vout' of a neighbor neuron to the swing node of the spiking neuron soma. Transistor Ms1 sets the gain or synaptic weight of the connection, while Ms2 controls the decay timing. The spike from a neighbor neuron injects charge onto the gate of Ms3 through Ms1 biased in the subthreshold region. This charge then slowly leaks away via Ms2, which is also subthreshold biased, to produce a decaying exponential current response through Ms3. The current is attached to the node of Fig. 1 and acts to modulate the threshold of the spiking neuron by pulling M3 closer to saturation, moving the effective threshold down since now a smaller membrane potential will trigger a spike. With slight modification the circuit can be made to source current to the swing node and produce an inhibitory connection.

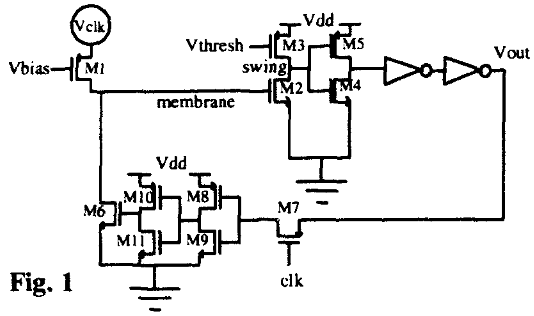

Fig. 1

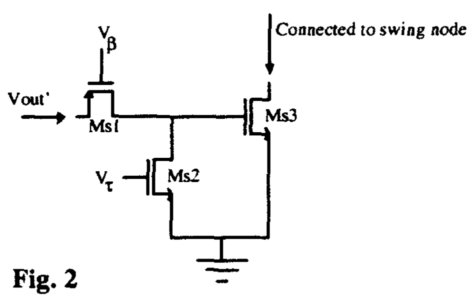

Fig. 2

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