Organic Spiking Neuromorphic Circuits: Flexible Embodied AI

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Artificial neurons are key components of neuromorphic computing systems, which aim to emulate the structure and functions of biological neural networks for efficient, brain-like computation. However, most artificial neurons rely on rigid, silicon-based technologies that are poorly suited for integration with soft structures, such as soft robots or biological systems, due to limitations in mechanical flexibility. Our aim is to develop networks of artificial spiking neurons, implemented using physically flexible organic electronics, to perform pattern recognition, processing of input/output data, and control of mechanical actuators. We have fabricated an electrical circuit that approximates the behavior of an Integrate-and-Fire (I&F) spiking neuron based on the Axon-Hillock model.[1] Utilizing complimentary p- and n-type organic transistor, the circuit integrates synaptic input current and produces output voltage spikes of a proportional frequency. We showed it encoding an analog concentration of an analyte of a chemical sensor into the frequency of output voltage spikes.[2] We verified that a somatic circuit is capable of generating tonic spikes enabling deep brain stimulation for altering the effects of neurological conditions, such as Parkinson's Disease.[3] We demonstrated physically flexible organic Log-Domain Integrator and Differential-Pair Integrator synaptic circuits.[4-5] Synapses, which convert input voltage spikes into output current traces, were characterized to demonstrate the effects of various synaptic parameters, including gain and weighting voltage, synaptic capacitance, and circuit response to inputs of various voltage spike frequencies. Time constants comparable to biological synapses, critical in processing real-world sensory signals were also shown. Furthermore, we reported the first organic spiking neuron fit with excitatory and inhibitory synapses and I&F soma. The circuit emulates key neural functions including pre-synaptic signal integration, frequency modulation, adjustable synaptic weighting, and coincidence detection. The neuron can interact with the real world in a light-control feedback loop that adjusts luminance based on ambient light intensity.

References

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