Organic, Spiking, and Flexible Embodied AI

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Embodied AI refers to artificial intelligence that is physically integrated into and interacts with the real world through sensors, actuators, and adaptive control systems. Artificial neurons are key components of neuromorphic computing systems, a type of embodied AI system, which emulate the structure and function of biological neural networks to achieve efficient, brain-inspired computation. Most artificial neurons are implemented using rigid silicon-based technologies, limiting their integration with soft robotic platforms and biological tissues because of their lack of mechanical flexibility. Our research aims to develop networks of artificial spiking neurons based on physically flexible organic electronics for pattern recognition, sensor data processing, and the control of mechanical actuators in embodied AI systems.

We have developed an electrical circuit that approximates the behavior of an Integrate-and-Fire (I&F) spiking neuron based on the Axon-Hillock model.[1] Using complementary p- and n-type organic transistors, the circuit integrates synaptic input currents and generates output voltage spikes with frequencies proportional to the input stimulus. We demonstrated its ability to encode the analog output of a chemical sensor into spike frequency, providing a biologically inspired interface between chemical sensing and neural computation.[2] We also verified that somatic circuit can generate tonic spike trains suitable for deep brain stimulation, with potential applications for treating neurological disorders such as Parkinson's disease.[3]

To emulate synaptic processing, we fabricated physically flexible organic Log-Domain Integrator and Differential-Pair Integrator synaptic circuits.[4–5] These synapses convert input voltage spikes into output current traces and were characterized with respect to key synaptic parameters, including gain, weighting voltage, synaptic capacitance, and responses to input spike frequencies. The circuits exhibited biologically relevant time constants that are essential for processing real-world sensory signals. Finally, we reported the first fully organic spiking neuron integrating excitatory and inhibitory synapses with an I&F soma. This system reproduces key neural functions, including pre-synaptic signal integration, frequency modulation, adjustable synaptic weighting, and coincidence detection. As a proof of embodied interaction, the neuron was incorporated into a closed-loop light-control system that autonomously adjusts luminance in response to ambient light intensity.

References

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