

Analog VLSI Simple Model Neuron with Wide Ranging Complex Dynamics

Moonjung Kyung¹, Eric Weiss¹, Venkat Rangan², and Gert Cauwenberghs¹

¹University of California San Diego, 9500 Gilman Dr., La Jolla, CA 92093

²Qualcomm Inc., 6455 Lusk Blvd., San Diego, CA 92121

Mathematical modeling of neural dynamics has been an invaluable tool in analyzing the behavior of neurons since its introduction by Hodgkin and Huxley more than fifty years ago. Despite the popularity of the Hodgkin-Huxley model, other models have been formulated that offer lower complexity in model implementation, and higher flexibility and fidelity in reconstructing experimentally observed neural dynamics over a large range of neuron types. A model with particularly low implementation complexity and high fidelity is one recently formulated by Izhikevich [1], which replicates the general dynamics of a wide range of neuron types by adjusting four parameters in a two-dimensional dynamical system. Although the simple quadratic form of the model is amenable to elegant and efficient implementation in analog very large scale integrated (VLSI) circuits, to date such implementation has not been reported.

Here we present the analog VLSI design of a neuron with programmable dynamics of the Izhikevich type [1]. The systematic design incurs the translinear principle [2] to implement multiplication terms in the quadratic dynamics using subthreshold metal-oxide-semiconductor (MOS) transistors with exponential dependence between voltage and current. The precise exponential dependence over six orders of magnitude in current [3] offers efficient implementation. We discuss the effects of parameter variations on the dynamics of the equations, and present simulation results that replicate several types of neural dynamics.

Most VLSI neurons to date have been designed to emulate the dynamics of either simple integrate-and-fire neurons [3] or of Hodgkin-Huxley neurons [4]. The Izhikevich model neurons with just four adjustable parameters are able to display a very wide range of behaviors, in contrast to more detailed models of neuronal dynamics such as Hodgkin-Huxley. VLSI implementation of a large network of these types of neurons (and their interconnecting synapses) promises to offer a highly customizable way to study systems of varying types of neurons.

[1] Izhikevich E.M. (2007) *Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting*. Cambridge MA: MIT Press. p. 274.

[2] Gilbert B. (1975). "Translinear circuits: a proposed classification". *Electronics Letters* **11** (1): 14–16.

[3] Mead C.A. (1989) *Analog VLSI and Neural Systems*. Addison-Wesley.

[4] Yu T. and Cauwenberghs G. (2009) "Analog VLSI Neuromorphic Network with Programmable Membrane Channel Kinetics," *Proc. IEEE Int. Symp. Circuits and Systems (ISCAS'2009)*, Taipei Taiwan (May 24–27, 2009).