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In the human brain, types of neurons are radically different. Complexities of neuronal cells are abstracted by a wide variety of methodology to help the understanding of the different aspects of neural networks' development, function, or learning. The neuronal model (also known as the spiking neuron model) is a mathematical description of the electrophysiological properties of neuronal cells, or neurons. It tries to accurately describe and predict their biological processes.

The first biologically relevant mathematical neuron model was proposed in 1952 by Hodgkin and Huxley (HH). Their four-dimensional set of equations describes the ionic conductance's dynamics of the giant axon, which are the starting point for detailed neuron models which account for numerous ion channels, different types of synapses, and the specific spatial geometry of an individual cell. Such class of models, conductance based models, successfully describe and reproduce the neuronal activity. The behavior of high-dimensional nonlinear differential equations, however, is difficult to visualize and even more difficult to analyze. Reduction of the ionic conductance models to low-dimensional and simple models has been thus highly important and has long research history that starts at the FitzHugh-Nagumo model. Several simple two-dimensional models have been recently introduced. They propose a trade-off between simplicity of equations and variation of dynamical behavior, each of them is optimized to specific activities to be effectively simulated. For instance, the Izhikevich model can qualitatively reproduce many different electrophysiological features of real neurons, such as spike-frequency adaptation, bursting, resonance, and rebound spiking. A variation of that model, the adaptive exponential integrate-and-fire model, includes an exponential spike initiation current, which is a realistic approximation of the sodium current. That model is able to quantitatively predict the responses of neuronal cells to inject currents in terms of spike times, with millisecond precision.

The quartic neuron model is another variant having a richer bifurcation diagram than above-mentioned models. Its equations are as simple as these models from the mathematical and computational points of view and also can exhibit sustained subthreshold oscillations. Various software solutions are currently available for simulating neuron models. Less conventional than software-based systems, hardware-based solutions are also provided which generally combine digital and analog forms of computation. Analog implementations are fast and efficient, they are inflexible, sensitive to variations and require a long development time. As in many other fields of microelectronics, a mixed implementation offers both the advantages and disadvantages of both solutions: analog circuits have a higher integration density, and digital platforms have better programmability. Recently, as a midpoint in the design space, FPGAs have been used to build spiking neuronal networks. Digital FPGA implementations offer a significant speedup over software designs, as well as size, weight, and power efficiency. Compared to analog VLSI, digital FPGAs designs are stable and flexible in design alterations.

This paper presents an FPGA implementation of the quartic neuron model. This approach uses digital computation to emulate individual neuron behavior. We implemented the neuron model using fixed point arithmetic operation. The neuron model's computations are performed in arithmetic pipelines. It was designed in VHDL language and simulated prior to mapping in the FPGA.

We show that the proposed FPGA implementation of the quartic neuron model can emulate the electrophysiological activities in various types of cortical neurons and is capable of producing a variety of different behaviors, with diversity similar to that of neuronal cells. The neuron family of this digital neuron can be modified by appropriately adjusting the neuron model's parameters.