Efficient, Scalable and Parallel Event-Driven Simulation Techniques for Complex Spiking Neuron Models

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The simulation of spiking neural networks (SNNs), both for neuro-biological and application based simulations, is known to be a very time consuming task. This limits the size of SNN that can be simulated in reasonable time or forces users to overly limit the complexity of the neuron models. This is one of the driving forces behind much of the recent research on event-driven simulation strategies.

Although event-driven simulation allows for precise and efficient simulation of certain spiking neuron models, it is not straightforward to generalize the technique to more complex neuron models, mostly because the firing time of these neuron models is computationally expensive to evaluate. Most solutions proposed in literature concentrate on algorithms that can solve this evaluation efficiently. However, these solutions do not scale well when more state variables are involved in the neuron model, which is, for example, the case when multiple synaptic time constants are used.

In more complex neuron models, e.g. conductance based neuron models, it is usually the case that the dynamics of the membrane potential cannot be solved analytically. This complicates the implementation of such models in an event-driven framework in order to benefit from the potentially high efficiency and accuracy of the event-driven simulation technique.

I. Event-driven simulation of complex neuron models

In this contribution, we will present an overview of several techniques that can be applied in order to significantly speed-up the event-driven simulation of complex neuron models. The overarching idea is to minimize the amount of performed computations that could later be invalidated by new input to the neuron.

In a first part, several techniques are represented that try to minimize the amount of work to predict the firing times of neuron models. Results are presented for Leaky Integrate-and-Fire (LIF) neurons with an arbitrary number of (unconstrained) synaptic time constants. The results show that thanks to these techniques, we can efficiently simulate neurons with a high number of state variables without sacrificing simulation speed [1].

In a second part, we show how we can deal with more complex neuron models. The solution basically tries to map a complex neuron model on neuron models that can be simulated efficiently in an event-driven manner. The error that arises by using such approximation methods can be successfully minimized by introducing an error-correction function. As an example, we show simulation results for a conductance based model with multiple synaptic time constants. Moreover, we show that the techniques of the previous part can also be applied on these models, resulting in a highly efficient and accurate method to compute complex neuron models in an event-driven framework.

II. Parallel event-driven simulation framework

In previous work [2] we have shown that large SNNs can be simulated very efficiently using digital parallel hardware architectures. However, these simulations used a time-step based framework, which limits the efficiency and precision of simulations. In an event-driven environment, it is less straight-forward to benefit from parallel computing.

An event-driven simulation is essentially an asynchronous proces. In order to ensure correct simulation results, events have to be processed in the correct temporal order. This introduces the need for synchronization mechanisms. Although these mechanisms are well studied in the computer science community, they have yet to be studied in detail and adapted for SNNs.

We present a SystemC-based framework for parallel event-driven simulation of SNNs. This framework allows to simulate different parallel environments (with an arbitrary number of computing nodes and programmable propagation delays) in order to test and optimize different synchronization mechanisms. An important aspect in this parallel approach is the application of the above proposed techniques, and the overall underlying idea of reducing computations that could later be invalidated by incoming spikes.

REFERENCES

[1] Michiel D'Haene, Benjamin Schrauwen, and Dirk Stroobandt. Accelerating event-driven simulation of spiking neurons with multiple synaptic time constants. *Neural Computation*, 2008. accepted.

[2] Benjamin Schrauwen, Michiel D'Haene, David Verstraeten, and Jan Van Campenhout. Compact hardware liquid state machines on FPGA for real-time speech recognition. *Neural Networks*, 21:511523, 2008.