IMPLEMENTING STDP ON A LAYERED SPIKING NEURAL NETWORK

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[1] INTRODUCTION

- Given a population of spiking neurons, how can we detect causal activity between neuron spikes and update their synaptic weights based on the activity observed?
- This is the motivating problem that Spike-timing-dependent plasticity (STDP) aims to answer.
- Overall STDP can be considered to be an algorithm that can help us in the updating the synaptic weights among neuron bodies.
- The aim of this project was to implement the Spike-Timing Dependent Plasticity algorithm on a layered Spiking Neuron Population. This implementation was done on the SpineCreator framework.
- SpineCreator[1,6] is a graphical framework for the creation, simulation and analysis of Spiking Neural Models. It is built on top of SpineML, an XML format that is used to specify Neural Models.

[2] THE IZHIKEVICH NEURON

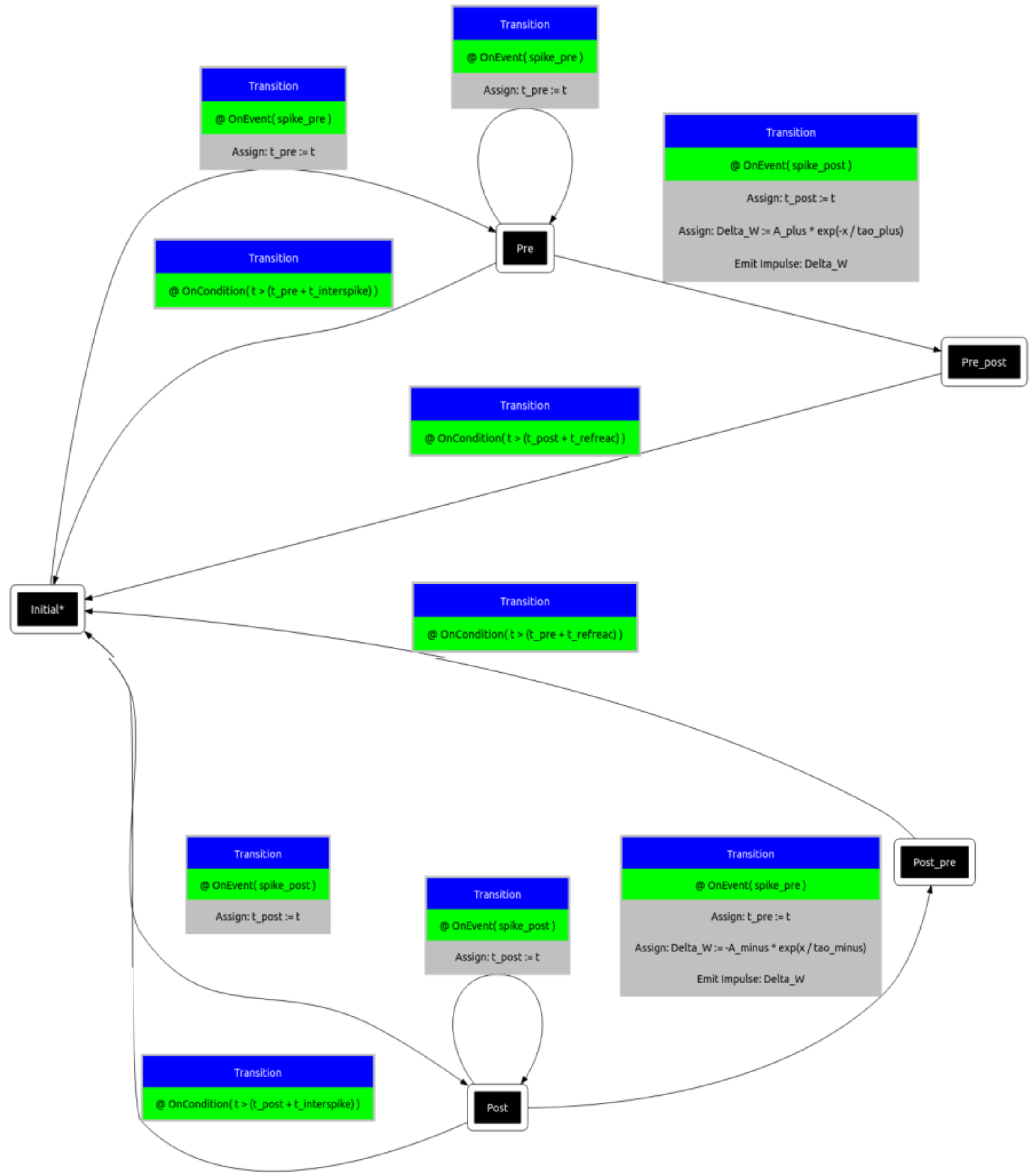
- We use the Izhikevich model of a Spiking Neuron[2] to simulate the Neuron Bodies on SpineCreator, as these models offer a sweet spot in terms of computational efficiency and biological plausibility.
- The Izhikevich model is specified by four parameters - a,b,c,d which for different values, produce different spiking patterns.
- The following equations govern the Izhikevich model:

$$
\begin{aligned}
v' &= 0.04v^2 + 5v + 140 - u + I \\
u' &= a(bv - u) \\
v &= c \\
u &= u + d
\end{aligned}
$$

  where equations 3,4 hold when $v >= 30mV$.
- We use the above equations to develop the Neuron-Body component on SpineCreator.

[4] THE WEIGHT UPDATE COMPONENT

Below is a schematic diagram of the Weight-Update component that implements STDP on the Izhikevich neuron.



[3] SPIKE TIMING DEPENDENT PLASTICITY

- As explained earlier, STDP is an extension of the Hebbian learning rule, as it imposes a time based ordering on the learning.
- A Pre-synaptic spike followed by a Post-synaptic spike strengthens the synapse.
- Conversely, A Post-synaptic spike followed by a Pre-synaptic one weakens the synapse.
- We quantify these relations with the following equations :

$$\begin{aligned} \Delta G &= +A_+ * e^{(-x/\tau_+)} && \text{if, } x >= 0 \\ \Delta G &= -A_- * e^{(-x/\tau_-)} && \text{otherwise.} \end{aligned}$$

  where $x = t_{post} - t_{pre}$.
- Thus by considering the relative timing of the spikes, the STDP learning rule is able to determine the update that should be done to the synaptic weights.

[5] THE MODEL STATES

- We build a five state model to implement STDP. The five states are described below :
  1. Initial : This is the default 'initial' state from where we begin our simulation.
  2. Pre : This is the state we obtain after encountering a Pre spike in the 'initial' state.
  3. Pre-Post : This is the state we obtain after encountering a Post spike in the 'pre' state. We update (increase) the synaptic weights on reaching this state.
  4. Post : This is the state we obtain after encountering a Post spike in the 'initial' state.
  5. Post-Pre : This is the state we obtain after encountering a Pre spike in the 'post' state. We again update (decrease) the synaptic weights on reaching this state.
- By switching between states and updating the synaptic weights on reaching the 'goal' states, we are able to consider the relative time between the Pre-synaptic and Post-synaptic spike.
- We do this by registering the spike-event-receiving-times that lead to a state transition. We also keep a track of the interspike interval, and revert back to the inital state in case of just a single lone spike.

[6] FURTHER WORK

- Further work would focus on more robust experiments with the implementation, and its application in different biologically motivated models, as a natural extension to previous work on similar models [4].
- The current implementation does not take neuro-modulation into account. However neuro-modulation is important for biologically inspired models[3,5] and thus a further extension would be to extend this implementation into a fully neuro-modulated one.

[7] ACKNOWLEDGMENTS

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