Towards replicating the mouse visual cortex in Neuromorphic Hardware

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Abstract

The primary visual cortex is one of the most complex parts of the brain offering significant modeling challenges.

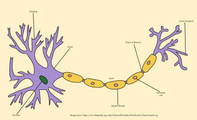
In an ongoing work, we proposed the implementation of the Leaky Integrate and Fire Model, based on data from Allen Institute of Brain Science (AIBS), into Intel's latest neuromorphic hardware, Loihi.

The architecture supports hierarchical connectivity, dendritic compartments and synaptic delays - the current LIF hardware abstraction in Loihi is a good match to the LIF model.

With the ongoing development of neuromorphic hardware, simulation of biologically realistic neuronal networks seems viable.

Brain Modeling Toolkit (BMTK)

A typical neuron consists of a soma (cell body), dendrites and a single axon. Neurons send signals (action potentials) down an axon to a dendrite through junctions called synapses.



The classical Generalized Leaky Integrate and Fire equation is one of the simplest and rather efficient representation of the dynamics of the neuron and is given as :

$$V'(t) = \frac{1}{C}\left[I_e(t) - \frac{1}{R}(V(t) - E_L)\right]$$

where,

- $V(t)$ = Membrane Potential
- C = Membrane Capacitance
- R = Membrane Resistance
- E_L = Resting Potential
- I_e = Membrane Current

According to [1], Generalized Leaky Integrate and Fire Models (GLIFs) are capable of reproducing cellular data under standardized physiological conditions. We use the **Brain Modeling Toolkit (BMTK)**, an efficient software package developed by the AIBS, to build and simulate GLIF model.

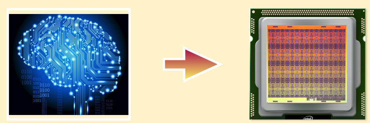
Loihi

Neuromorphic Hardware

A hardware inspired by the structure and functionality of the brain, envisioned to provide advantages such as low power consumption, low fault tolerance and massive parallelism for the next generation of computers.

Loihi

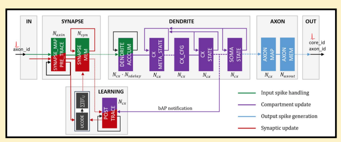
In the end of 2017, Intel Corporation unveiled its neuromorphic chip called Loihi. This chip forms the basis for our work.



www.gepezz.info   Image from : wikichip.org

Brain-inspired Loihi Chip (right)

It is a 60-mm² chip that uses an asynchronous spiking neural network, comprising of **128 neuromorphic cores**, **3 x86 cores**, along with several off-chip communication interfaces that provide connectivity to other chips [2].



Loihi Internal Neuron Model - 1 of the 1024 neural units comprising the core.

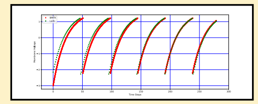
Results

Loihi follows fixed-point modeling as opposed to conventional chip modeling in float. The work here investigates how one compares to the other.

First, we check the implementation of a one-neuron network in both BMTK and Loihi, in the presence of a constant membrane current. Next, we examine the simulation of a two-cell network driven by external spikes.

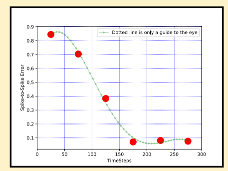
I. Constant Membrane Current

Simulation of One Neuron



Simulation of membrane voltage of one neuron using same LIF parameters on the BMTK and Loihi platform yields almost identical spikes.

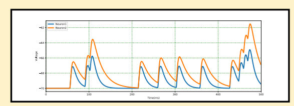
Error between the spikes in each bin



Considering the 10th quantile as a good estimate, the error seems to decrease with the simulation runtime, giving a **Mean Square Error of 0.1318**.

II. Variable External Spikes

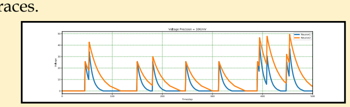
Simulation of a Two-Neuron Network

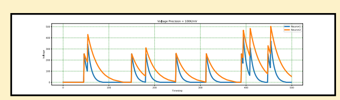


Simulation of membrane voltage on BMTK, providing the basis for comparisons. Following simulations are on Loihi.

Simulation using different voltage precisions

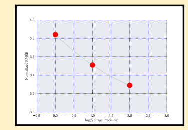
BMTK and Loihi follow different dynamics, for external spike stimulus. After a spike, BMTK uses an alpha-function whereas Loihi uses a step and exponential decay. This leads to difference in spike traces.





Voltage scales linearly, proportional to the precision.

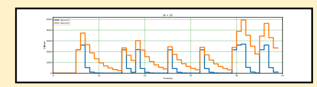
Error comparison for voltage precisions

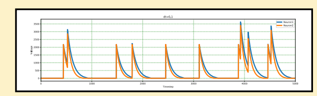


We run simulations based on precisions 1K, 10K, 100K, 1000K – for 1mV of simulation voltage. Error decreases as precision increases.

Simulation using different temporal precisions

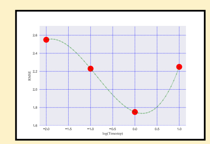
Loihi follows a fixed simulation time-step. We assign different time units to each step and test the corresponding simulation precision.





Increasing the precision smoothens the emulation.

Error comparison for temporal precisions



Error is lowest when 1ms of simulation time equates to 1 physical time-step. Reducing the time step further doesn't necessarily better the emulation.

Conclusion

- Loihi produces results comparable to BMTK.
- Due to architecture differences, exact state replication may be difficult.
- In future work, we plan to assess spike-based metrics.

References

1. Generalized leaky integrate-and-fire models classify multiple neuron types, Teeter C. et al.(2018), Nature Communications 9:709.
2. Loihi : A Neuromorphic Manycore Processor with On-Chip Learning, Davies M. et al.(2018), IEEE Micro, 38:1.