Learnable intra-layer feedback response in SNNs

Anton-David Almasan
Data Scientist, *Thales UK*
Email: anton-david.almasan@uk.thalesgroup.com

1 Background and Motivation

An event based camera is a bio-inspired imaging sensor that is able to bring multiple considerable advantages over traditional frame capturing cameras in areas such as dynamic range, motion blur mitigation and sensing latency. The recent developments in this field alongside an increasing interest in low-powered neuromorphic hardware such as the Intel Loihi chip constituted a solid motivation for various academic groups to pursue researching the capabilities of Spiking Neural Networks (SNNs).

1.1 Spiking neural networks

An SNN is a nonlinear function that uses a biologically inspired mathematical neuron model to augment traditional Artificial Neural Networks (ANNs) in a way that allows processing of asynchronous spike-type input data and learnable temporal dependencies. The role of the neuron model is to convert a train of discrete input spikes into continuous neuron dynamics which guide the *activation* of a neuron (i.e. a discrete output spike train). This is shown schematically in Figure 1.

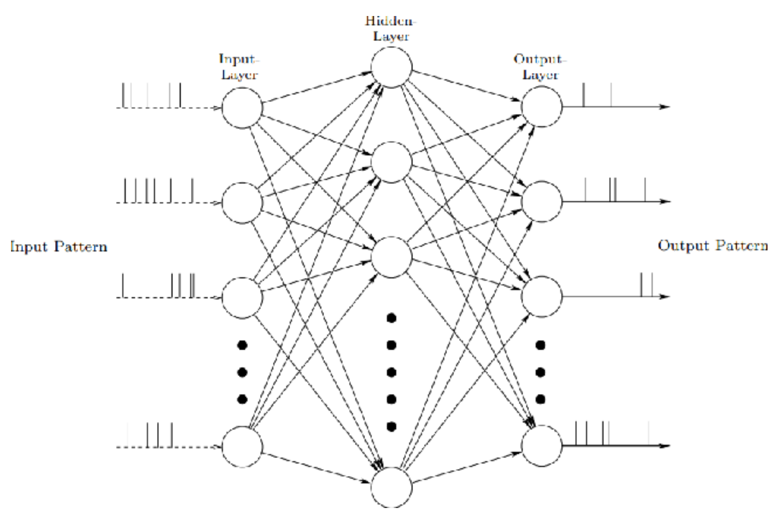

Figure 1: Schematic of a Spiking Neural Network

1.2 Kernels

In the spiking neuron model, the neuron dynamics are controlled by *kernels*. A detailed description of this model is presented by Shrestha et al in SLAYER [1]. In short, a neuron's internal response, or **membrane potential** to an incoming spike is a continuous signal comprised of the convolution between the input signal and the neuron's *excitatory* and *inhibitory* kernels. If the membrane potential reaches a set threshold, the neuron outputs a spike.

2 Proposed research

Alongside the ability to process data asynchronously, a strong point of SNNs is the ability to model complex temporal correlation given the versatile nature of the kernels. We wish to augment this capability, having [1] as a baseline. Our work has focused on feed forward SNNs so far, and our scope is currently comprised of introducing the following items:

1. **Learnable intra-layer dependencies**: Creating an intra-layer feedback system for an SNN allows neurons from the same layer to receive gradient signals during training (i.e. a neuron can learn to activate more often or not not only from the signal received from the previous layers, as is custom in a traditional Artificial Feed Forward Network (FNN), but also from the feedback signals shared between the neurons in the same layer), thus allowing for the development of *layer-specific memory*. Our current research on this indicates that this extension introduces significant learnable gradient signals that get backpropagated in the network during training

2. **Spike function derivative reformulation**: The spike function derivative introduced in [1] represents a key *theoretical* point for using backpropagation in SNN training. Besides having found comments in the open-source SLAYER [1] repository indicating that the introduction of this derivative in the backpropagation pipeline downgrades the performance, we have found though that there are changes which can be introduced to make it more mathematically robust.

3. **CNN extension**: We wish to also extend the above two concepts to Convolutional Spiking Neuronal Networks

To summarise, we can structure the proposed research bid into 2 sections:

- **Work Package 1: Mathematical research**: This would involve defining the mathematical formulation explored in **Items 1** and **2** above, with a complete model for the forwards and backwards passes within an SNN with *Learnable intra-layer dependencies*

- **Work Package 2: Code implementation**: Starting from the SLAYER [1] open-source code repository, we have done work on implementing the framework outlined in **Work Package 1** using CUDA/PyTorch. Further work on this is needed, with extensive knowledge in C++/CUDA being essential

References

[1] S. B. Shrestha and G. Orchard. SLAYER: spike layer error reassignment in time. *CoRR*, abs/1810.08646, 2018.