Analysis of Neurons' Information in Deep Spiking Neural Networks using Information Theory

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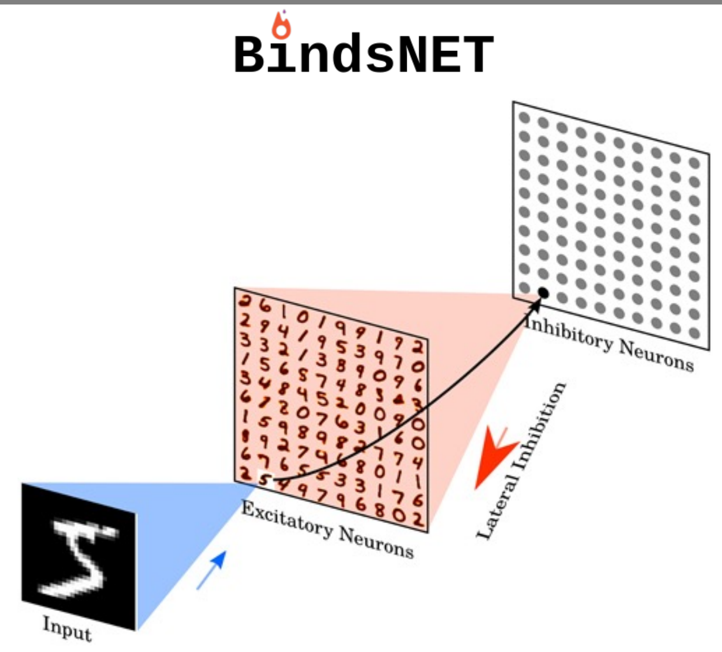
Introduction

- SNNs can be seen as a more biologically realistic approach than artificial neural networks (ANNs)

- SNNs typically require fewer operations, are more energy-efficient, and more hardware-efficient, making them very appealing for the future

- One of the current problems with these kinds of networks is the difficulty in training them since they are non-differentiable and therefore the backpropagation algorithm cannot be used

Architecture



This architecture is composed of:

- An input layer, that contains 28x28 or 32x32 neurons
- A processing layer, composed of a variable, but equal, number of excitatory and inhibitory neurons

Images are modelled as a Poisson spike-train and are fed into the excitatory layer

Information Theory

The definition of entropy is the expected information content of random variable X:

$$H(X) = -\sum_{x} p_X(x) log_2[p_X(x)]$$

The joint entropy of two random variables X and Y is defined as:

$$H(X,Y) = -\sum_{x,y} p(x,y) log_2[p(x,y)]$$

The mutual information between two random variables X and Y, is related to entropy as follows:

$$I(X;Y) = H(X) + H(Y) - H(X,Y)$$

Training

$$\Delta w = \eta(x_{pre} - x_{tar})(w_{max} - w)^{\mu}$$

Each synapse keeps track of the synaptic weight, w, and the presynaptic spike history, x_{pre}

- Every time a presynaptic spike arrives at the synapse, the trace (x_{pre}) is increased by 1 and it decays exponentially

The higher the target value, the lower the synaptic weight will be

- This offset promotes that presynaptic neurons that rarely lead to the firing of the postsynaptic neuron will become more and more disconnected

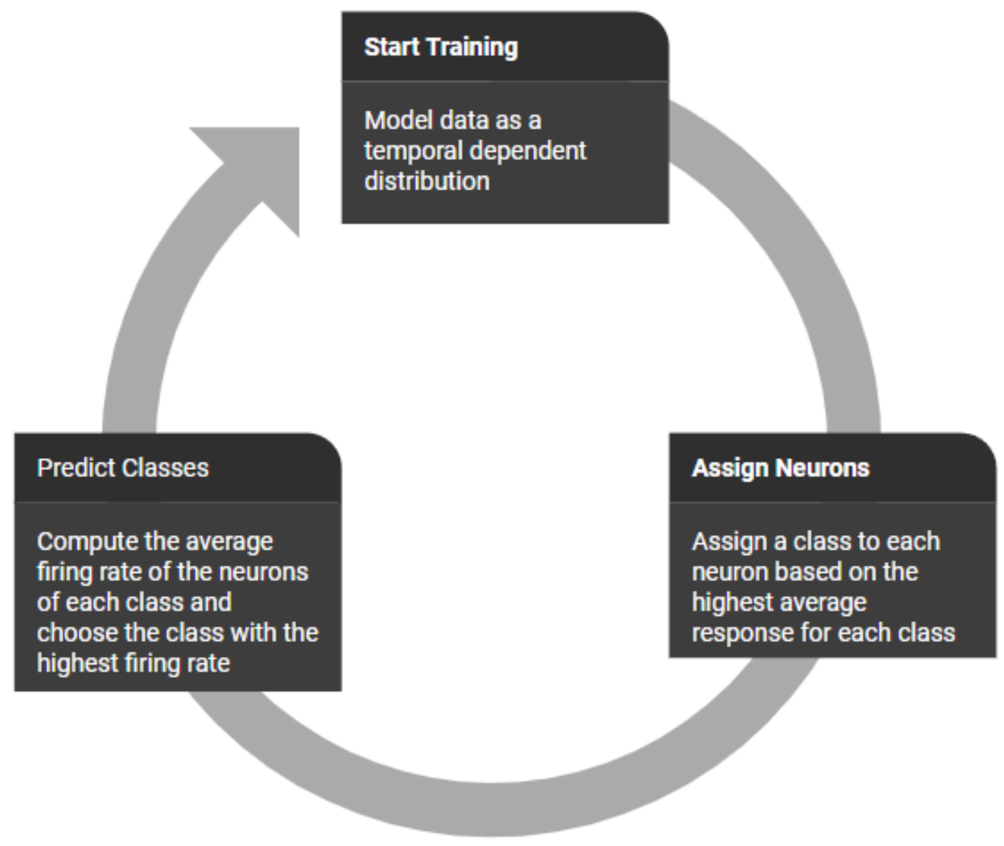
Each excitatory neuron's membrane has a value of Θ added to the threshold value v_{thr}, therefore the final threshold of an excitatory neuron becomes $v_{thr + \Theta}$

- Θ is increased every time the neuron fires and decays exponentially
- Neurons that fire very frequently will have a higher membrane threshold, making them require more inputs to spike soon

$$\frac{dv_{mem}(t)}{dt} = \sum_{i} \sum_{s \in S_i} w_i \delta(t - s)$$

A spike is generated if the membrane crosses a given threshold v_{thr}

The membrane voltage is then reset to a reset potential v_{res}



Results, Discussion and Conclusions

Table 2. Relationship between the index of the neurons that spiked on the output layer, and the index of the output neurons that have mutual information with the input of the network.

	MNIST		Fashion-MNIST		CIFAR-10	
Class	Output neurons that spiked	Neurons with mutual information	Output neurons that spiked	Neurons with mutual information	Output neurons that spiked	Neurons with mutual information
0	{3, 4, 29, 31, 52}	{3, 4, 29, 31, 52}	{22, 24, 64, 67, 85}	{22, 24, 64, 67, 85}	{1, 18, 20, 90}	{1, 18, 20, 90}
1	{8, 97}	{8, 97}	{7, 11, 16, 65, 67, 72, 87}	{7, 11, 16, 65, 67, 72, 87}	{}	{}
2	{23, 71, 85}	{23, 71, 85}	{4, 12, 29, 32, 66, 71}	{4, 12, 29, 32, 66, 71}	{18}	{18}
3	{2, 7, 14}	{2, 7, 14}	{11, 65, 67, 72, 87}	{11, 65, 67, 72, 87}	{45, 73}	{45, 73}
4	{32, 65, 80, 94}	{32, 65, 80, 94}	{}	{}	{}	{}
5	{32, 37, 67, 75, 78}	{32, 37, 67, 75, 78}	{}	{}	{}	{}
6	{17, 28}	{17, 28}	{2, 15, 19, 39}	{2, 15, 19, 39}	{11, 28}	{11, 28}
7	{18, 26, 92, 99}	{18, 26, 92, 99}	{77}	{77}	{}	{}
8	{11, 33, 35, 90}	{11, 33, 35, 90}	{3, 21, 96, 97}	{3, 21, 96, 97}	{1, 18, 23, 36}	{1, 18, 23, 36}
9	{38, 65, 94}	{38, 65, 94}	{0, 21, 92}	{0, 21, 92}	{1, 14, 18, 23}	{1, 14, 18, 23}

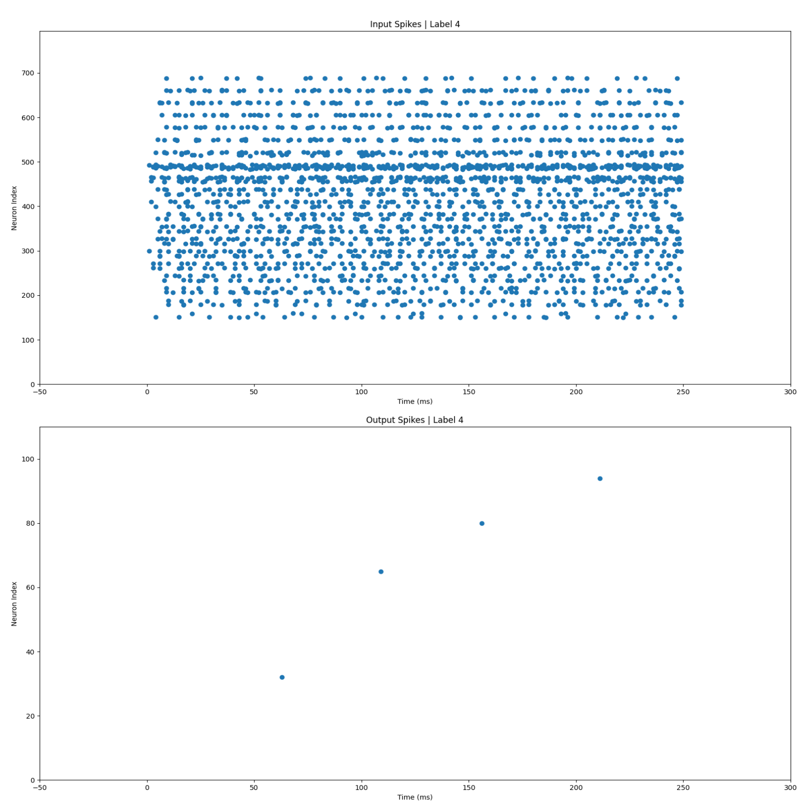


Table 1. Accuracy performances obtained by the SNN trained on different data sets.

Dataset	Accuracy (%)
MNIST	72
Fashion-MNIST	46
CIFAR-10	9

This work presented an exploratory study with the SNN model proposed by Diehl et al. in three benchmark data sets

Results suggest that the output neurons that present higher values of mutual information related to the input neurons are the ones that fire when given an image of a certain class, which confirms our initial intuition

Further work should be developed to the improvement of the accuracy performances

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