Three Factor Delay Learning Rules For Spiking Neural Networks

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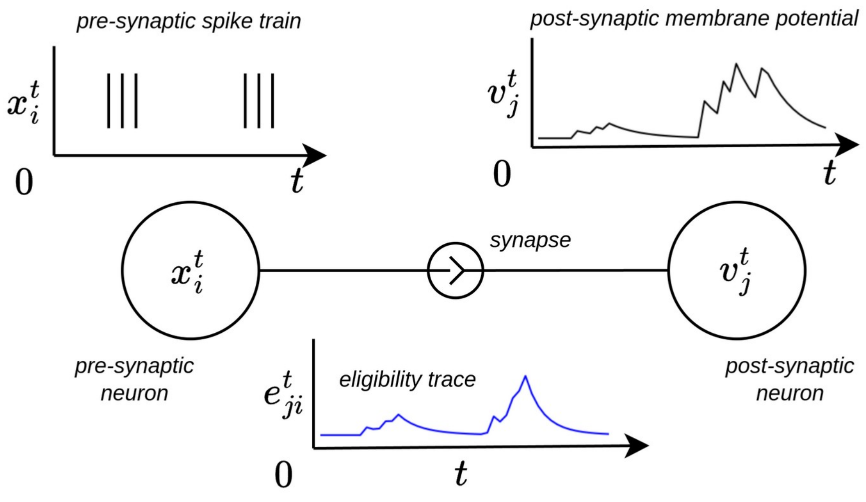
Background & Motivation
Three factor learning rules

- Three factors
  - Pre-synaptic spike train
  - Post-synaptic membrane potential
  - Learning signal



- Offer some gradient equivalence

- Suitable for real-time / online implementation

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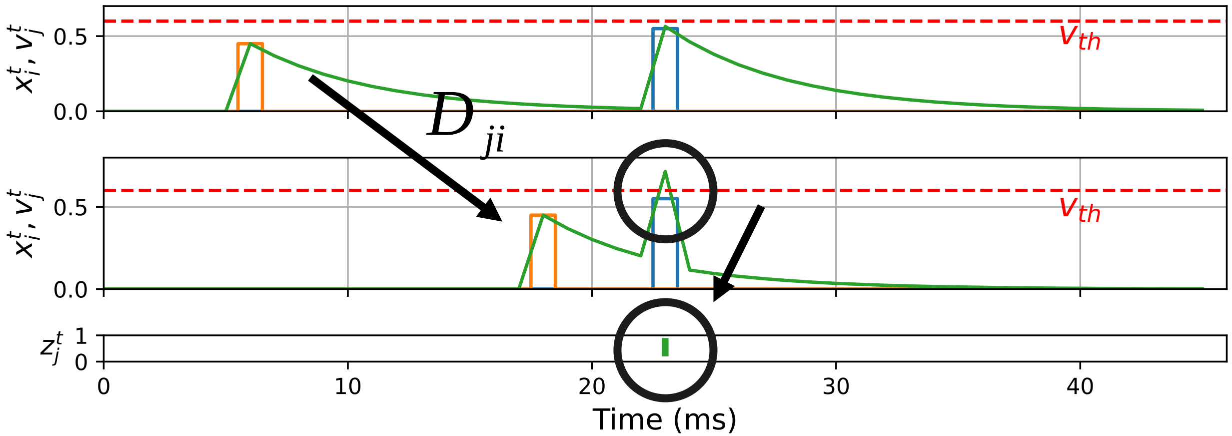
Gerstner et al. (2018), “Eligibility Traces and Plasticity on Behavioral Time Scales: Experimental Support of NeoHebbian Three-Factor Learning Rules

Background & Motivation
Delay learning

- Exclusive parameter set for temporal features
- Can lead to significant accuracy improvement in temporal tasks
- Smaller model sizes



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Bellec et al. (2020), “A solution to the learning dilemma for recurrent networks of spiking neurons”

Method – Eligibility Propogation

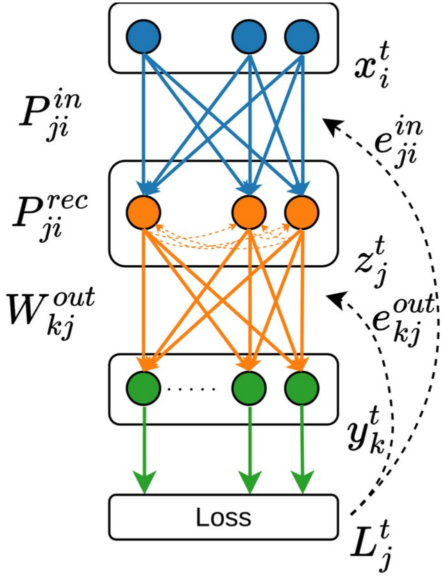
$$\tau_m \frac{dv_j}{dt} = -(v_j(t) - v_{reset}) + RI_j(t) \longrightarrow v_j^{t+1} = \alpha v_j^t + W_{ji}^{\text{in}} x_i^{t - D_{ji}^{\text{in}}}$$

$$\frac{dE}{dP_{ji}} = \frac{dE}{dz_j} \times \frac{dz_j}{dv_j} \times \frac{dv_j}{dP_{ji}}$$

$$\frac{dE}{dP_{ji}} = L_j^t e_{p,ji}^t$$

Learning Signal

Eligibility trace



$$P_{ji} \in \{W_{ji}, D_{ji}, D_i\}$$

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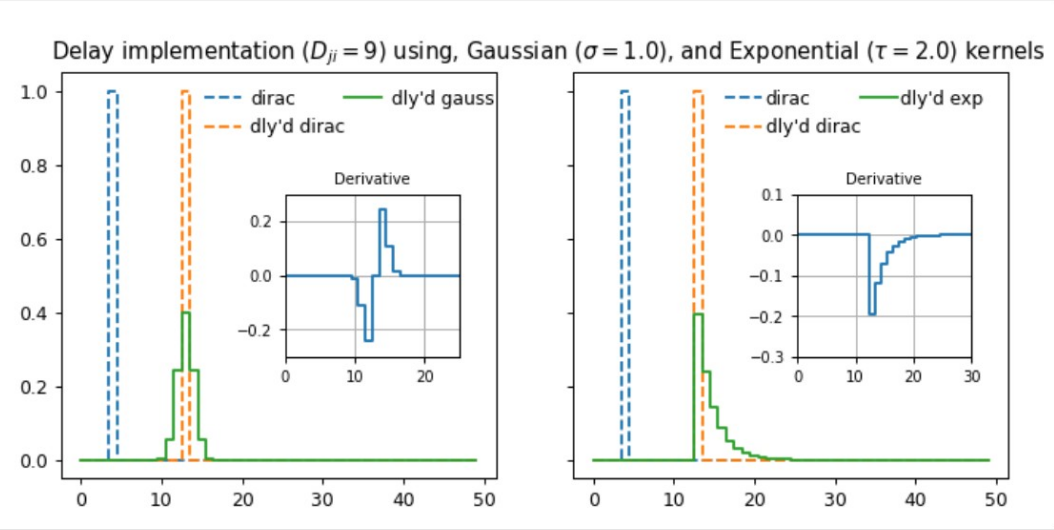
Method

Non-differentiable spikes

$$v_j^{t+1} = \alpha v_j^t + W_{ji}^{\mathrm{in}} x_i^{t - D_{ji}^{\mathrm{in}}}$$

$$x_i^{t - D_{ji}} = \sum_k \delta\left(t - t_k - D_{ji}\right)$$

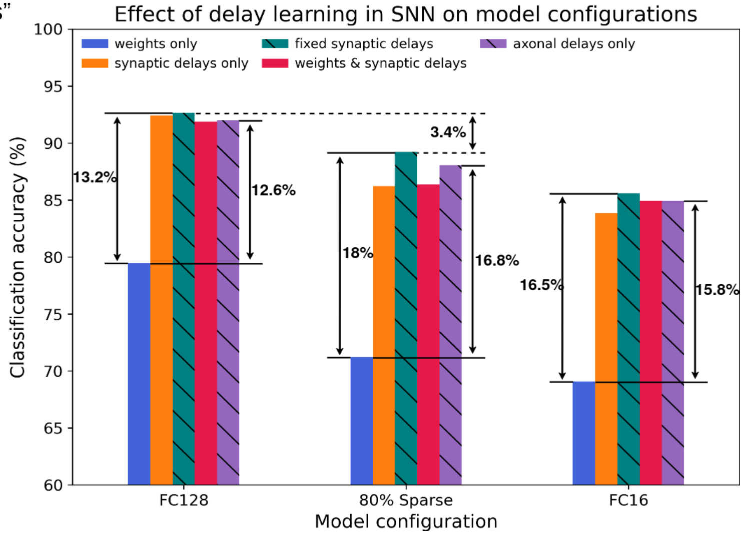
$$x_i^{t - D_{ji}} \approx \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{\left(t - t_k - D_{ji}\right)}{2\sigma^2}}$$

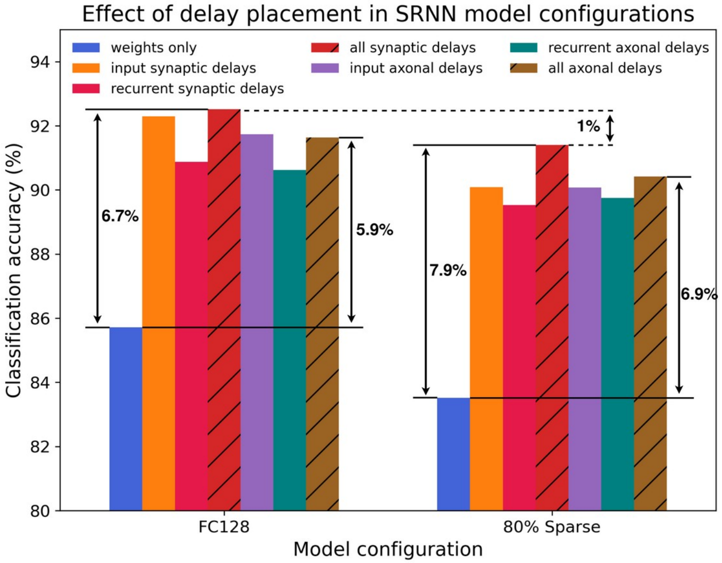


[1] Cramer et al. (2022), “The Heidelberg spiking datasets for the systematic evaluation of spiking neural networks”
[2] Hammouamri et al. (2024), "Learning Delays in Spiking Neural Networks using Dilated Convolutions with Learnable Spacings"

Results

- Synaptic and axonal delays
- Feedforward and recurrent SNNs
- Spiking Heidelberg Digits Dataset[1]
- BPTT-based offline baseline[2]





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Conclusions

- Three factor learning rules for synaptic and axonal delays
- On audio classification tasks parameter heterogeneity enables:
  - Smaller models
  - Higher accuracy

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Thank you for your attention

Questions?