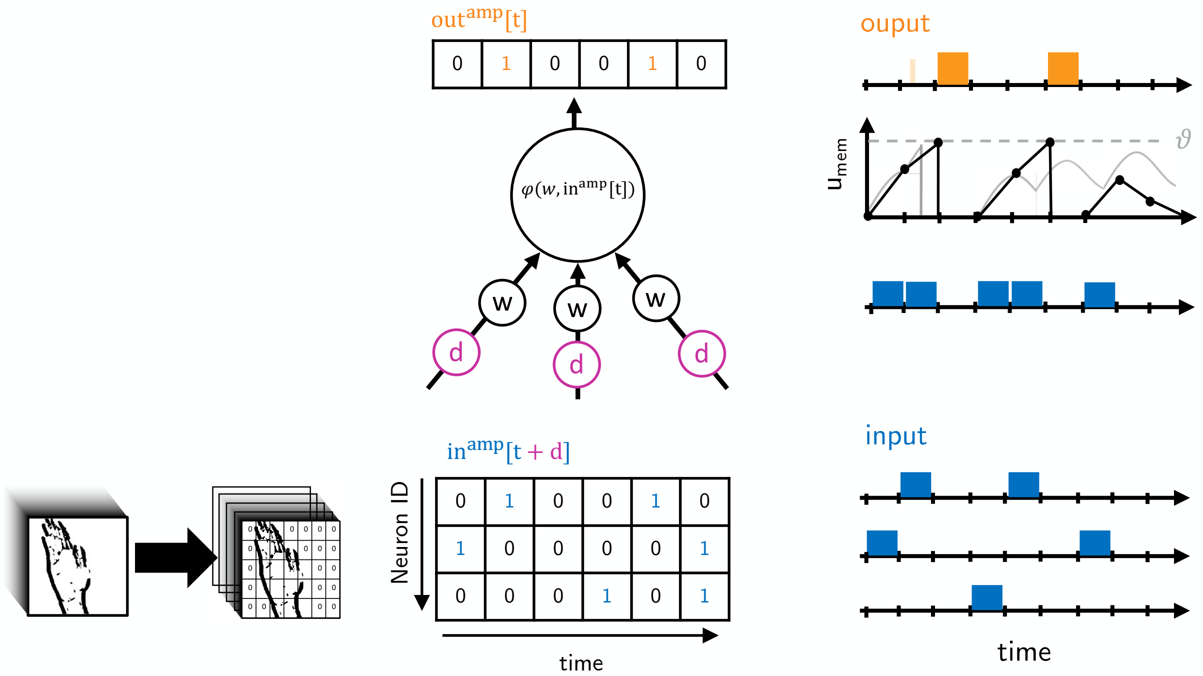
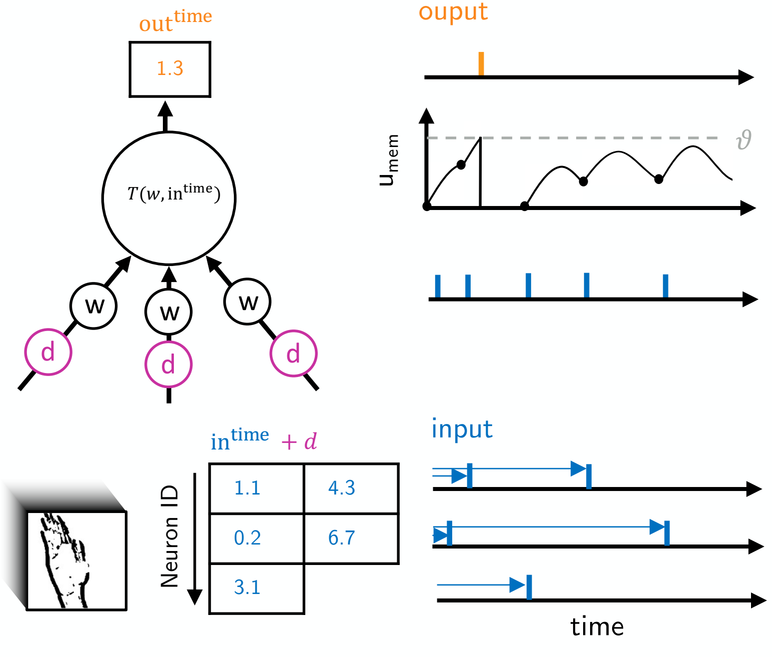
DelGrad: Exact event-based gradients in spiking networks for training delays and weights

Julian Göltz, Jimmy Weber, Laura Kriener, Sebastian Billaudelle, Peter Lake, Johannes Schemmel, Melika Payvand and Mihai A. Petrovici.

Time step framework [1]



Event-based framework [2]



Gradients for the delays

$$\frac{\partial\mathcal{L}}{\partial d} = \frac{\partial\mathcal{L}}{\partial \mathrm{out}^{\mathrm{amp}}[t]} \boxed{\frac{\partial \mathrm{out}^{\mathrm{amp}}[t]}{\partial \mathrm{in}^{\mathrm{amp}}[t+d]}} \boxed{\frac{\partial \mathrm{in}^{\mathrm{amp}}[t+d]}{\partial d}}$$

Surrogate Gradient

Non differentiable

- Exact at forward (precise timings)
- Exact at backward (differentiable ⇒ exact gradients).
- Complexity scales with events sparsity.
- Fewer observables: only the spike timings (HW-friendly).
- Natural training of delays

Gradients for the delays

$$\frac{\partial\mathcal{L}}{\partial d} = \frac{\partial\mathcal{L}}{\partial \mathrm{out}^{\mathrm{time}}[t]} \frac{\partial \mathrm{out}^{\mathrm{time}}[t]}{\partial (\mathrm{in}^{\mathrm{time}}+d)} \boxed{\frac{\partial (\mathrm{in}^{\mathrm{time}}+d)}{\partial d}}$$

Trivial: $=1$

[1] Neftci, E. O. et al. Bringing the power of gradient-based optimization to spiking neural networks. (2019).
[2] Goltz, J., Kriener, L., et al. Fast and energy-efficient neu- romorphic deep learning with first-spike times. (2021).

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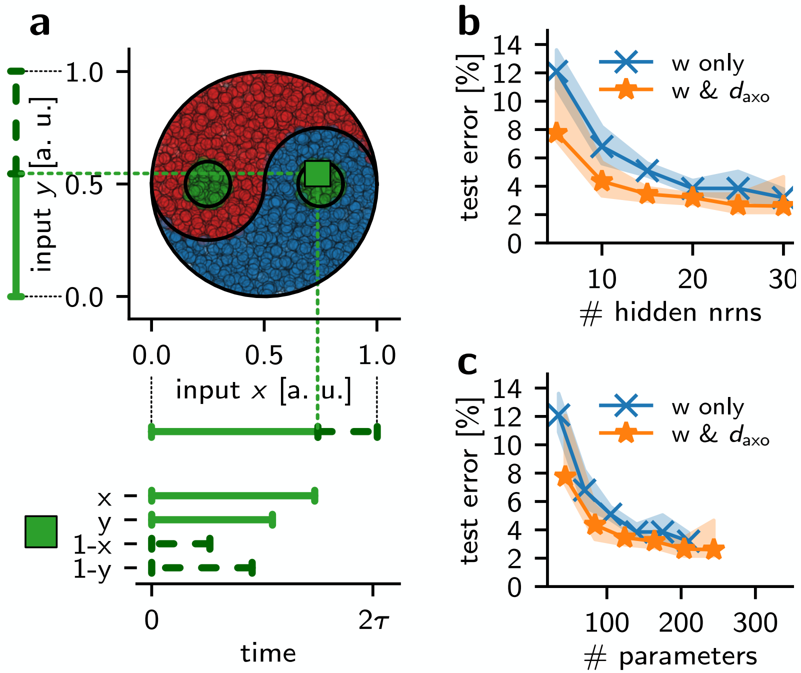
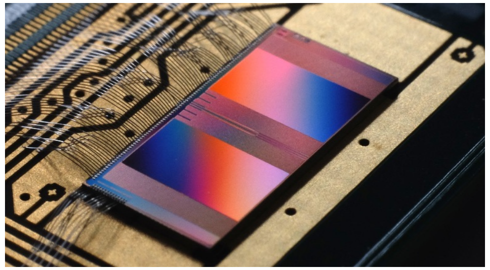
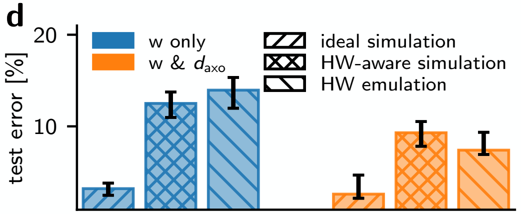
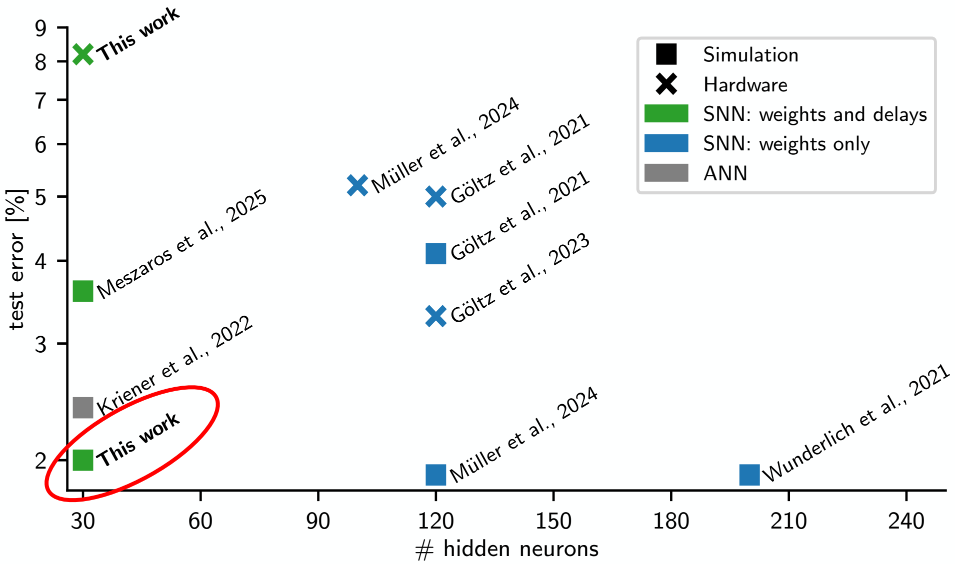
Results





BrainScaleS-2 [4]





- Assessed on the Yin-Yang Dataset [3]
- Better performance with reduced number of parameters
- Demonstrate successful training with HW in-the-loop
- Outperform State-of-the-art on the Yin-Yang Dataset

[4] Kriener, L. et al. The Yin-Yang Dataset. (2022).
[3] Pehle, C. et al. The BrainScaleS-2 Accelerated Neuromorphic System with Hybrid Plasticity. (2022)