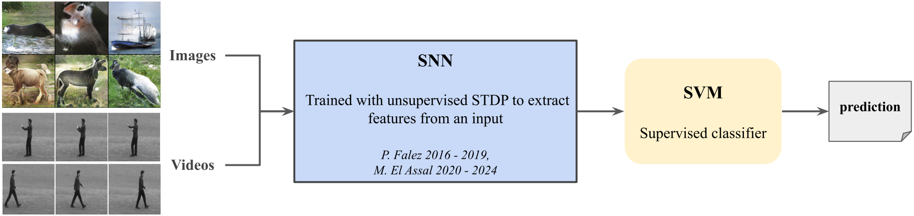
Paired Competing Neurons Improving STDP Supervised Local Learning In Spiking Neural Networks

Gaspard Goupy, Ioan Marius Bilasco, Pierre Tirilly

Univ. Lille, CNRS, Centrale Lille, UMR 9189 CRIStAL, F-59000 Lille, France

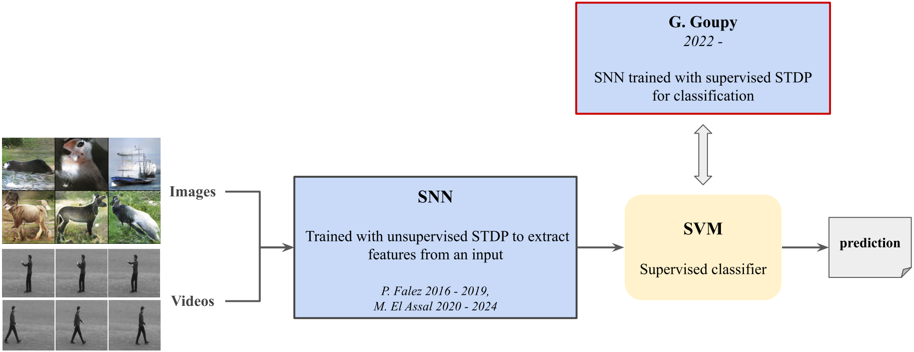
Context



STDP: Spike-Timing Dependent Plasticity

SVM: Support Vector Machine

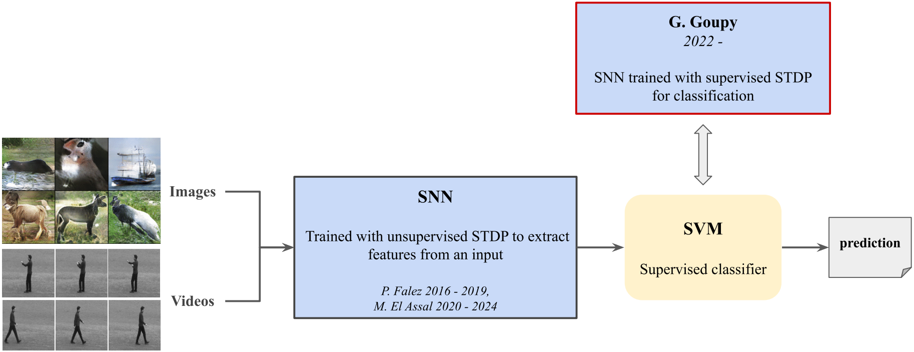
Context



STDP: Spike-Timing Dependent Plasticity

SVM: Support Vector Machine

Context

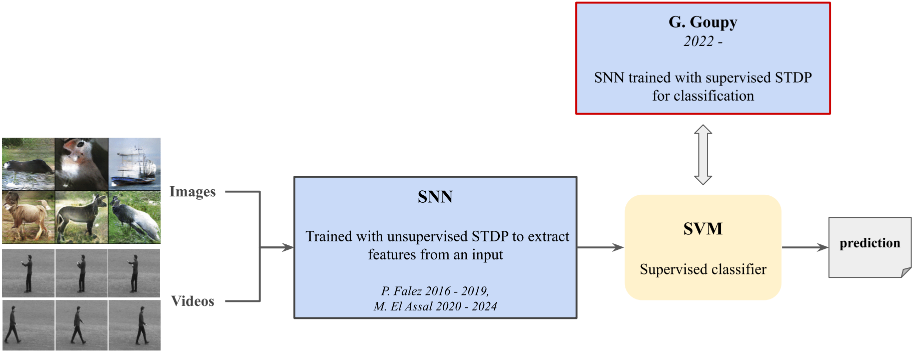


→ **End-to-end SNN models that lessen the use of supervised learning**

STDP: Spike-Timing Dependent Plasticity

SVM: Support Vector Machine

Context



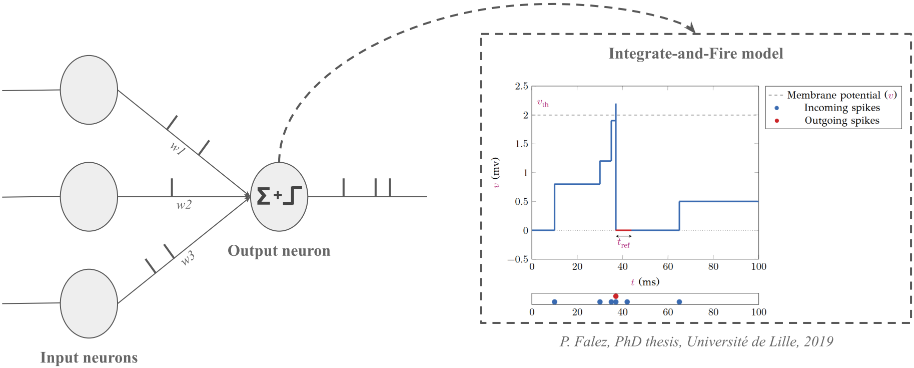
→ **End-to-end SNN models that lessen the use of supervised learning**

→ **Supervised learning compatible with neuromorphic hardware**

STDP: Spike-Timing Dependent Plasticity

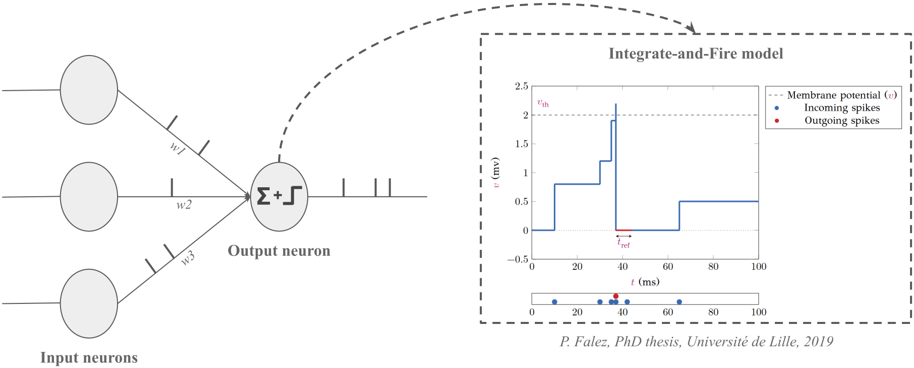
SVM: Support Vector Machine

Spiking Neural Networks (SNNs)



P. Falez, PhD thesis, Université de Lille, 2019

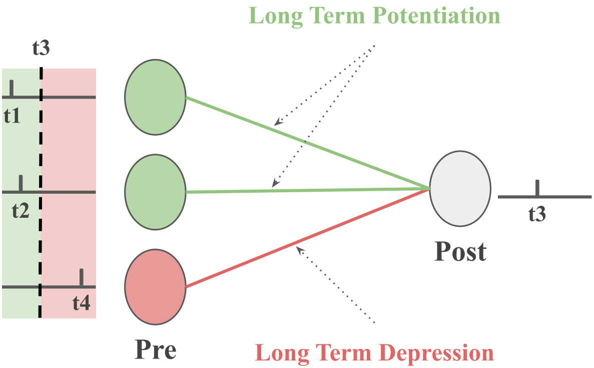
Spiking Neural Networks (SNNs)



P. Falez, PhD thesis, Université de Lille, 2019

➔ **In our models: one spike per neuron**

Spike-Timing Dependent Plasticity (STDP)

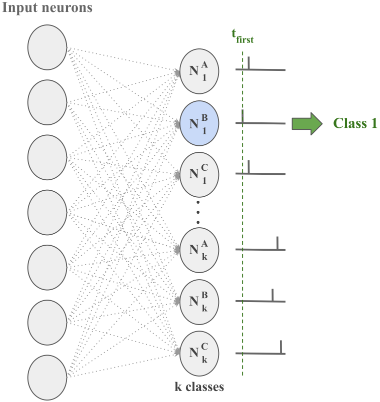


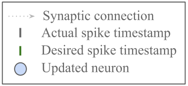
Supervised learning with STDP

State-of-the-art rules

Supervised learning with STDP

State-of-the-art rules





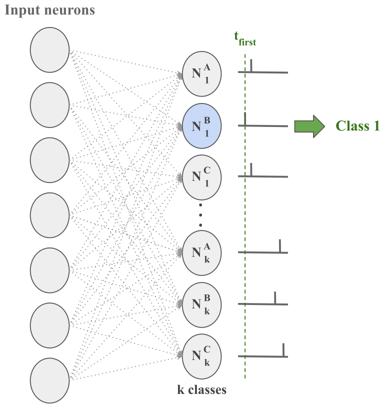
Reward-modulated STDP (R-STDP)

$\Delta W = \text{sign} \times \text{STDP}$

[Mozafari et al. 2018]

Supervised learning with STDP

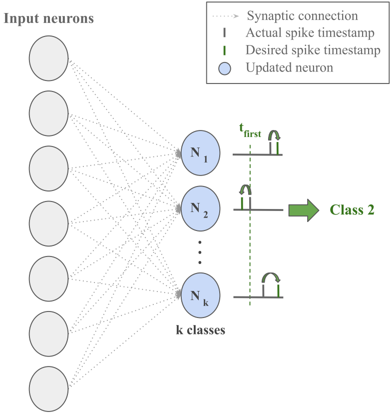
State-of-the-art rules



Reward-modulated STDP (R-STDP)

$\Delta W = \text{sign} \times \text{STDP}$

[Mozafari et al. 2018]



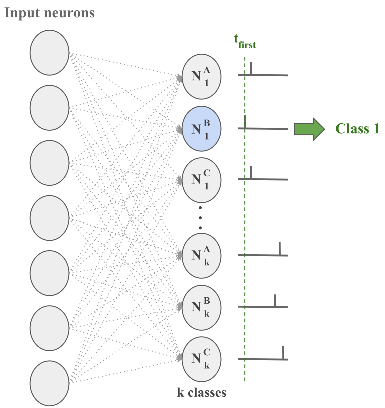
Supervised STDP (SSTDP)

$\Delta W = \text{error} \times \text{STDP}$

[Liu et al. 2021]

Supervised learning with STDP

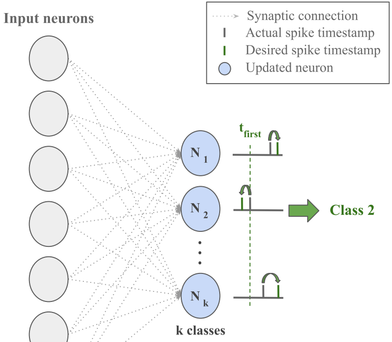
State-of-the-art rules



Reward-modulated STDP (R-STDP)

ΔW = sign × STDP

[Mozafari et al. 2018]



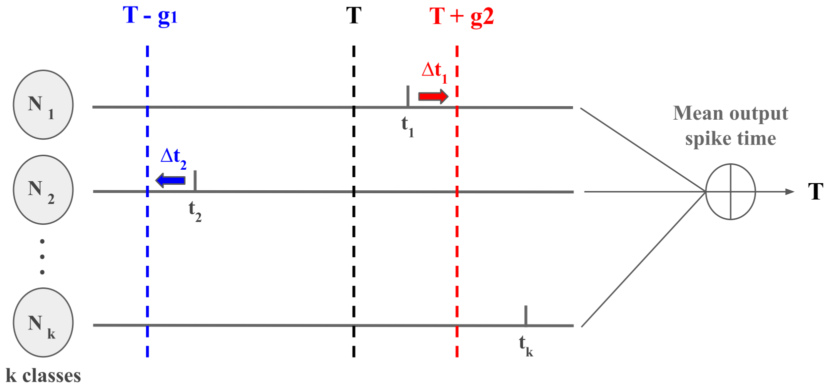
Supervised STDP (SSTDP)

ΔW = error × STDP

[Liu et al. 2021]

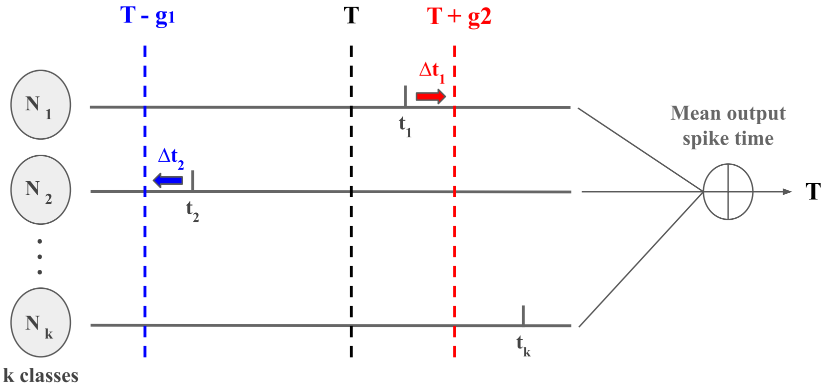
→ **SSTDP: less neurons, more updates, more accurate**

Supervised learning with STDP
Supervised STDP (SSTDP)



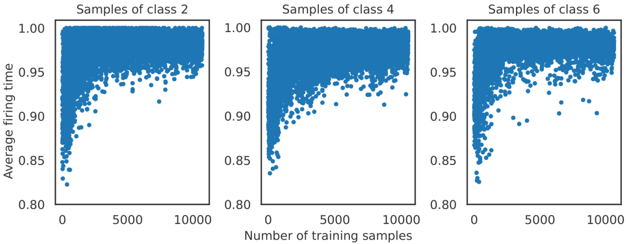
Supervised learning with STDP

Supervised STDP (SSTDP)

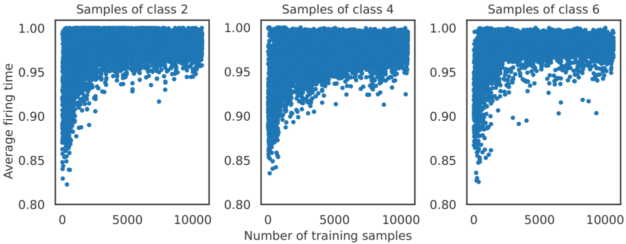


→ **Neurons that reach their target time range are not updated**

Supervised learning with STDP
Supervised STDP (SSTDP)



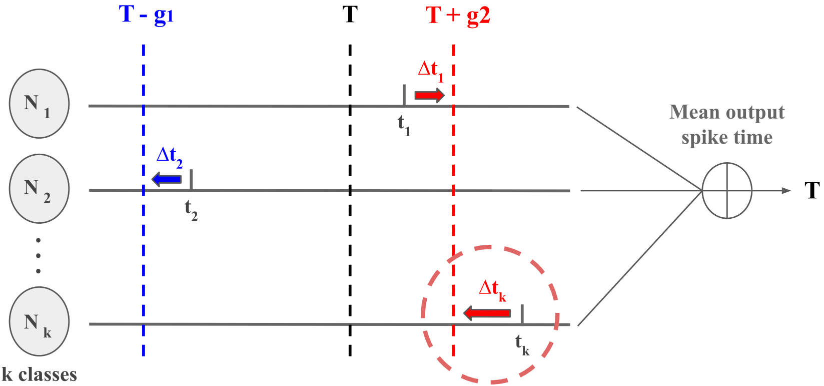
Supervised learning with STDP
Supervised STDP (SSTDP)



➔ **Saturation of the firing timestamps toward the maximum time**

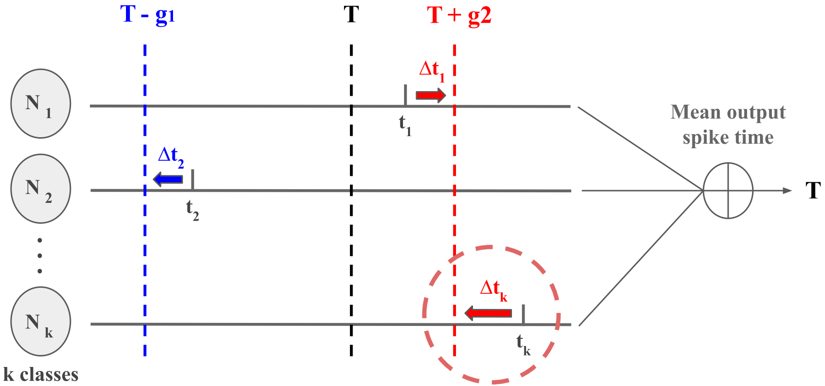
Contributions

Stabilized Supervised STDP (S2-STDP)



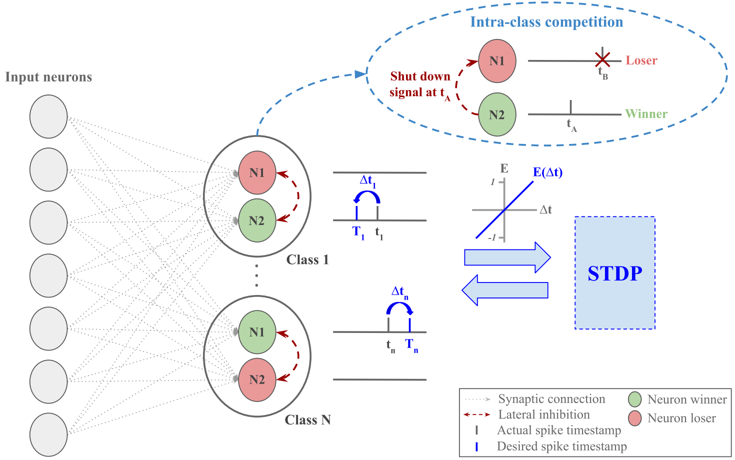
Contributions

Stabilized Supervised STDP (S2-STDP)



→ **Neurons are updated to reach the exact target time**

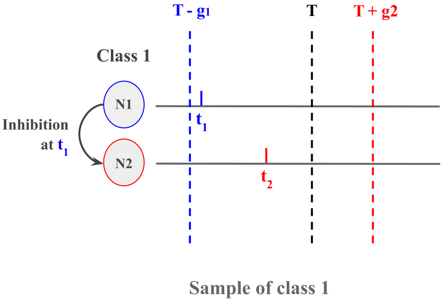
Paired Competing Neurons (PCN)

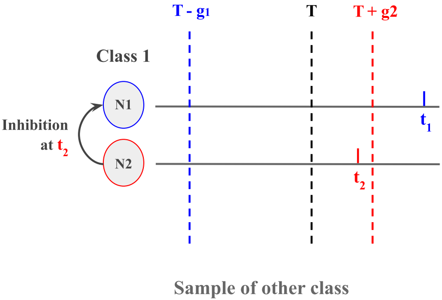


Contributions
Paired Competing Neurons (PCN)

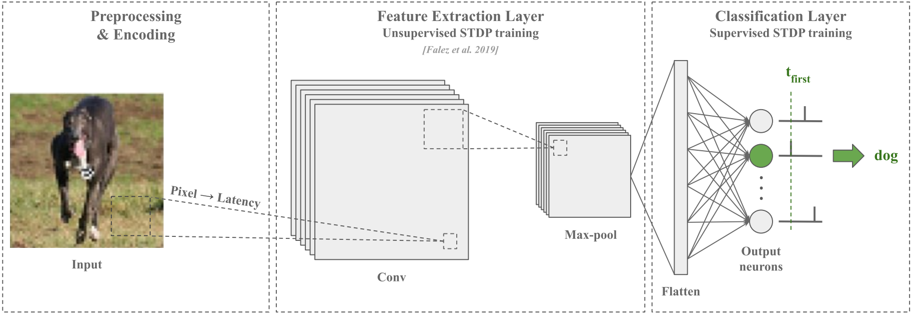
Goal: promote neuron specialization on target or non-target samples through intra-class competition

Goal: promote neuron specialization on target or non-target samples through intra-class competition





Results
Model



Results

Accuracy

Rule	MNIST	Fashion-MNIST	CIFAR-10
R-STDP (N=200)	97.88 ± 0.13	83.26 ± 0.22	**65.56 ± 0.38**
R-STDP (N=20)	93.28 ± 0.87	77.01 ± 0.22	54.02 ± 0.80
SSTDP	96.37 ± 0.09	84.12 ± 1.11	61.34 ± 0.14
S2-STDP[1]	97.81 ± 0.05	85.88 ± 0.22	61.53 ± 0.16
S2-STDP+PCN[1]	**98.59 ± 0.06**	**87.12 ± 0.21**	62.81 ± 0.15
SVM	98.93 ± 0.04	89.30 ± 0.21	65.50 ± 0.29

[1] Our method

Results

Accuracy

Rule	MNIST	Fashion-MNIST	CIFAR-10
R-STDP (N=200)	97.88 ± 0.13	83.26 ± 0.22	**65.56 ± 0.38**
R-STDP (N=20)	93.28 ± 0.87	77.01 ± 0.22	54.02 ± 0.80
SSTDP	96.37 ± 0.09	84.12 ± 1.11	61.34 ± 0.14
S2-STDP[1]	97.81 ± 0.05	85.88 ± 0.22	61.53 ± 0.16
S2-STDP+PCN[1]	**98.59 ± 0.06**	**87.12 ± 0.21**	62.81 ± 0.15
SVM	98.93 ± 0.04	89.30 ± 0.21	65.50 ± 0.29

→ **S2-STDP outperforms SSTDP**

[1] Our method

Results

Accuracy

Rule	MNIST	Fashion-MNIST	CIFAR-10
R-STDP (N=200)	97.88 ± 0.13	83.26 ± 0.22	**65.56 ± 0.38**
R-STDP (N=20)	93.28 ± 0.87	77.01 ± 0.22	54.02 ± 0.80
SSTDP	96.37 ± 0.09	84.12 ± 1.11	61.34 ± 0.14
S2-STDP[1]	97.81 ± 0.05	85.88 ± 0.22	61.53 ± 0.16
S2-STDP+PCN[1]	**98.59 ± 0.06**	**87.12 ± 0.21**	62.81 ± 0.15
SVM	98.93 ± 0.04	89.30 ± 0.21	65.50 ± 0.29

→ **S2-STDP outperforms SSTDP**

→ **PCN further improves S2-STDP performance**

[1] Our method

Results

Accuracy

Rule	MNIST	Fashion-MNIST	CIFAR-10
R-STDP (N=200)	97.88 ± 0.13	83.26 ± 0.22	$\mathbf{65.56 \pm 0.38}$
R-STDP (N=20)	93.28 ± 0.87	77.01 ± 0.22	54.02 ± 0.80
SSTDP	96.37 ± 0.09	84.12 ± 1.11	61.34 ± 0.14
S2-STDP[1]	97.81 ± 0.05	85.88 ± 0.22	61.53 ± 0.16
S2-STDP+PCN[1]	$\mathbf{98.59 \pm 0.06}$	$\mathbf{87.12 \pm 0.21}$	62.81 ± 0.15
SVM	98.93 ± 0.04	89.30 ± 0.21	65.50 ± 0.29

→ **S2-STDP outperforms SSTDP**

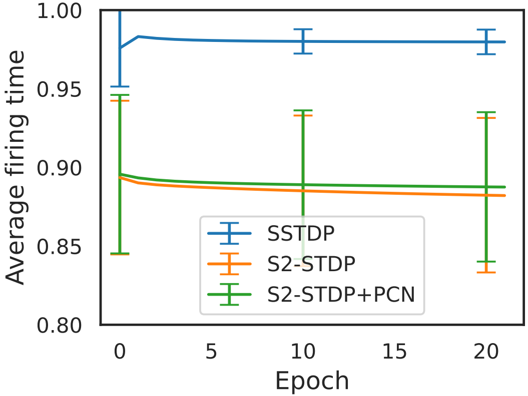
→ **PCN further improves S2-STDP performance**

→ **S2-STDP+PCN outperforms R-STDP for similar architectures**

[1]Our method

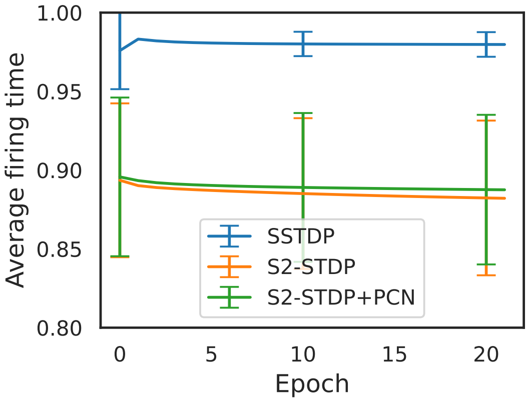
Results

Impact on the firing timestamps (MNIST)



Results

Impact on the firing timestamps (MNIST)



→ **S2-STDP reduces the saturation effect**

Conclusion

Objective

- Train a spiking classifier using a supervised adaptation of STDP

Contributions

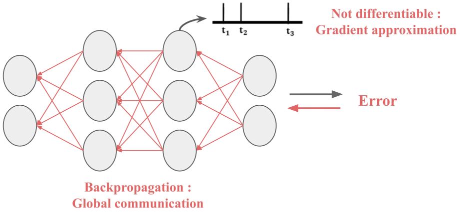
- S2-STDP: a learning rule adapted from SSTDP that reduces the saturation effect
- PCN: a training architecture that improves the learning capabilities of our classifier

Perspectives

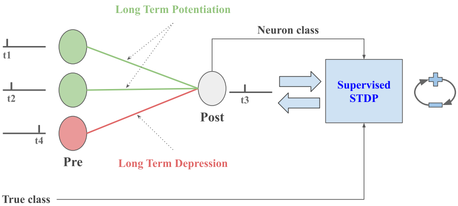
- Multi-layer local supervised learning with STDP
- Classification tasks with DVS data

G. Goupy, P. Tirilly, I.M. Bilasco, *Paired Competing Neurons Improving STDP Supervised Local Learning In Spiking Neural Networks*, 2023.
https://arxiv.org/abs/2308.02194

Supervised learning in SNNs



BP-based

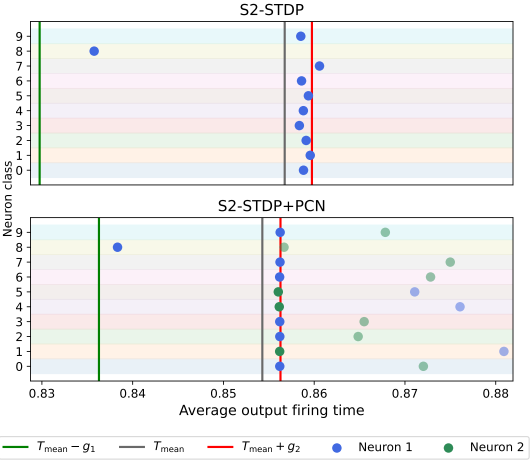


STDP-based

	BP-based	**STDP-based**
Good performance	✓	✗
Efficient computation/memory	✗	✓
No gradient approximation	✗	✓
Local communication	✗	✓
Easy switch to unsupervised learning	✗	✓

Results

Impact on the firing timestamps (MNIST)



→ **PCN are better at reaching their targets**