



Backpropagation-free Spiking Neural Networks with the Forward-Forward Algorithm

M Ghader et al.



2026.10.08

Overview



01 Author & Journal

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05 Limitations & Future Directions



Mohammadnavid Ghader

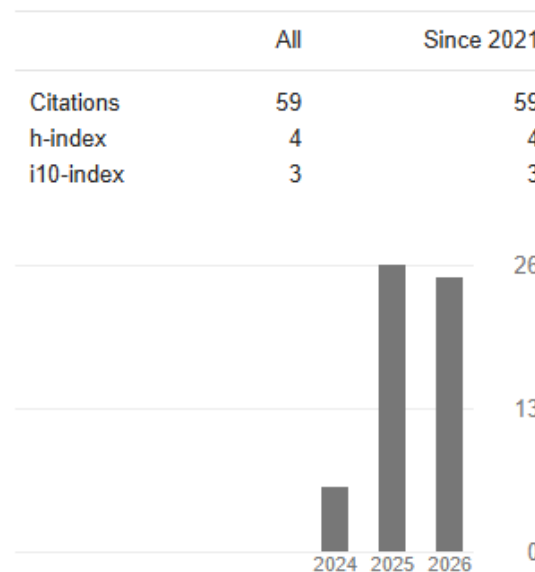
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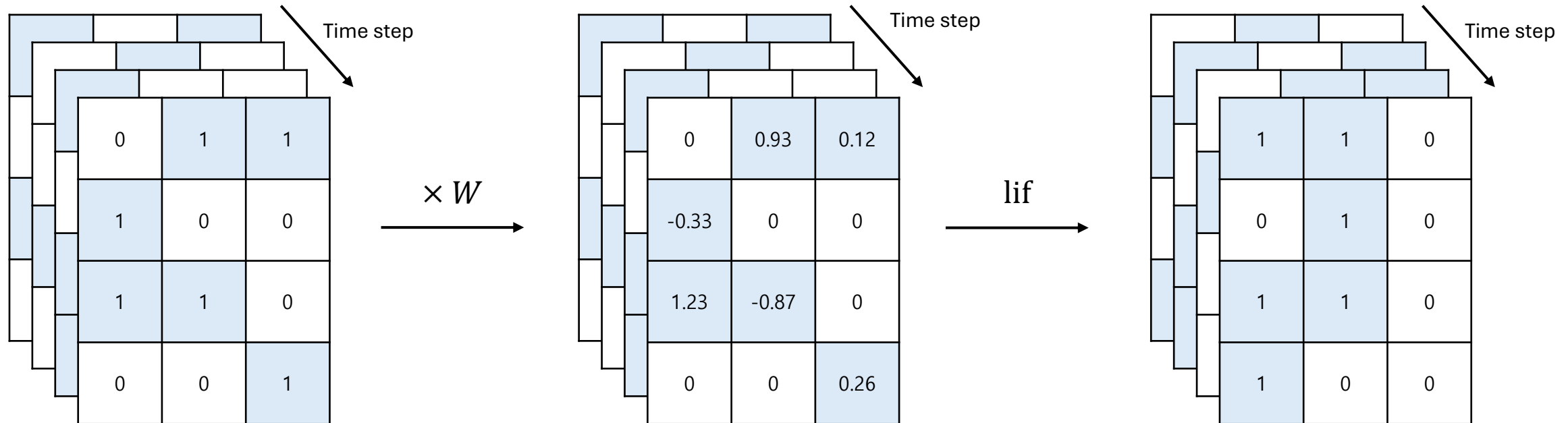
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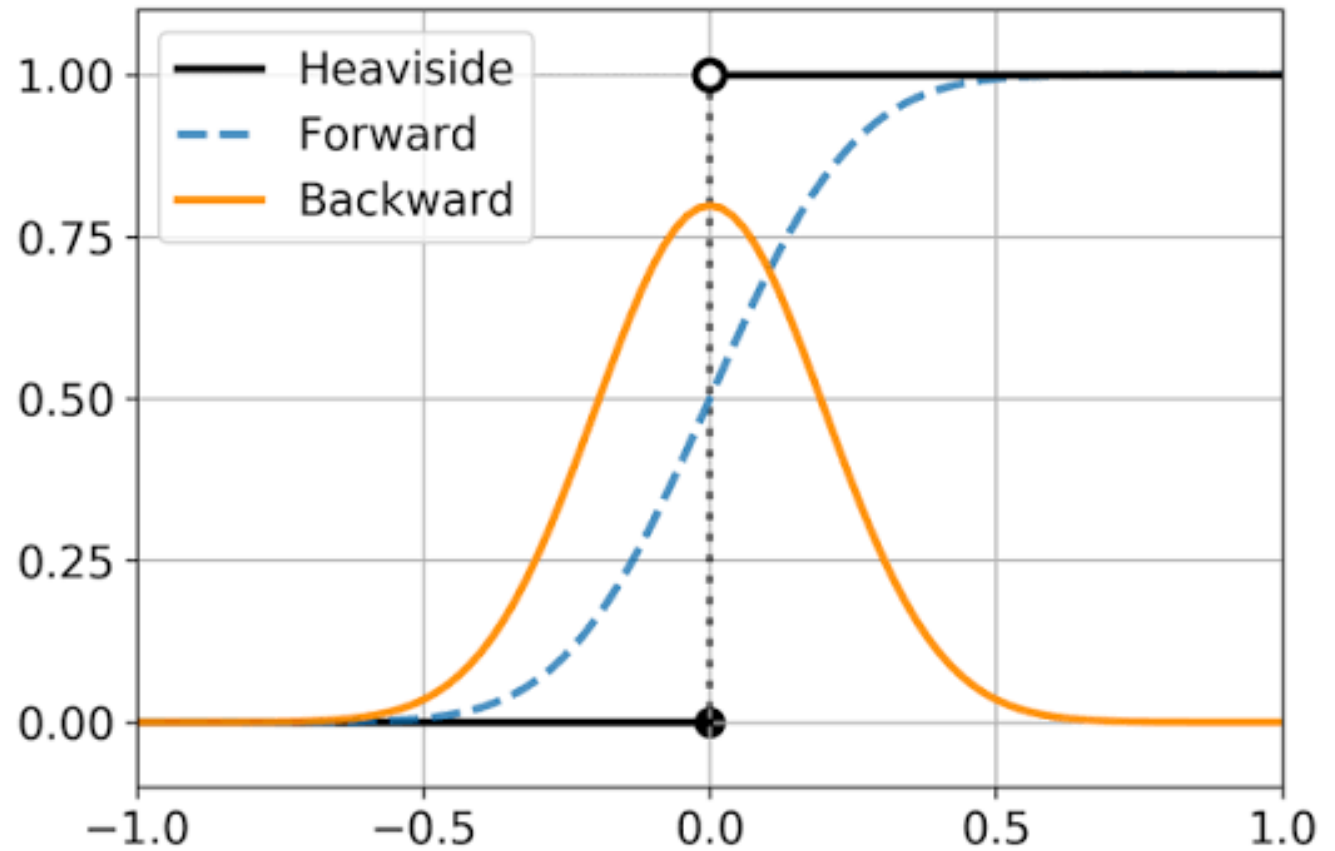
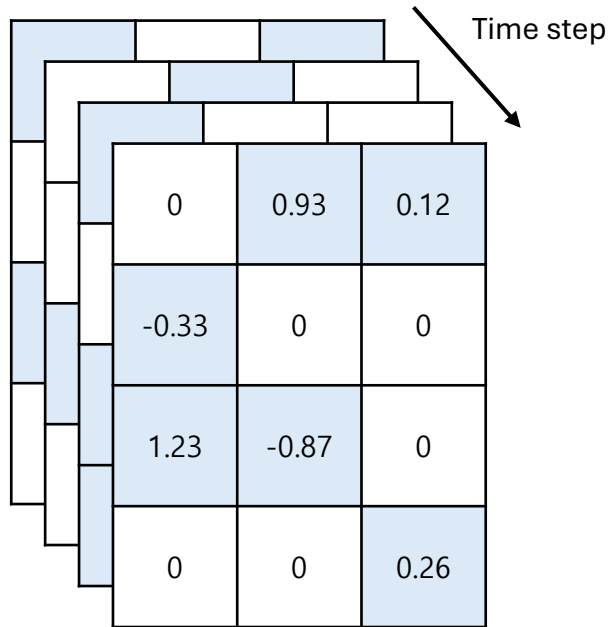
TITLE	CITED BY	YEAR
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Backpropagation-free spiking neural networks with the forward-forward algorithm M Ghader, SR Kheradpisheh, B Farahani, M Fazlali Scientific Reports 16 (1), 14294	18	2026
Enabling privacy-preserving edge ai: Federated learning enhanced with forward-forward algorithm M Ghader, SR Kheradpisheh, B Farahani, M Fazlali 2024 IEEE International Conference on Omni-layer Intelligent Systems (COINS ...	13	2024
Principal and independent component analysis methods M Ghader, M Abdolmaleki, HD Mazraeh Dimensionality Reduction in Machine Learning, 65-107	6	2025

1) Spiking Neural Networks

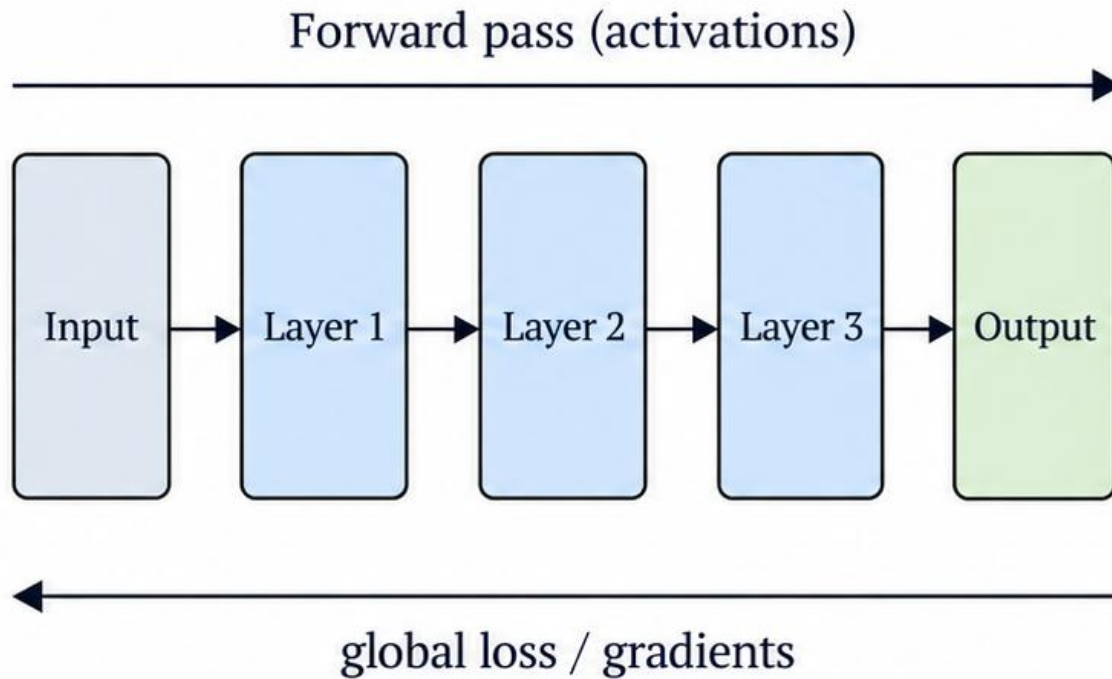


2) Surrogate gradient

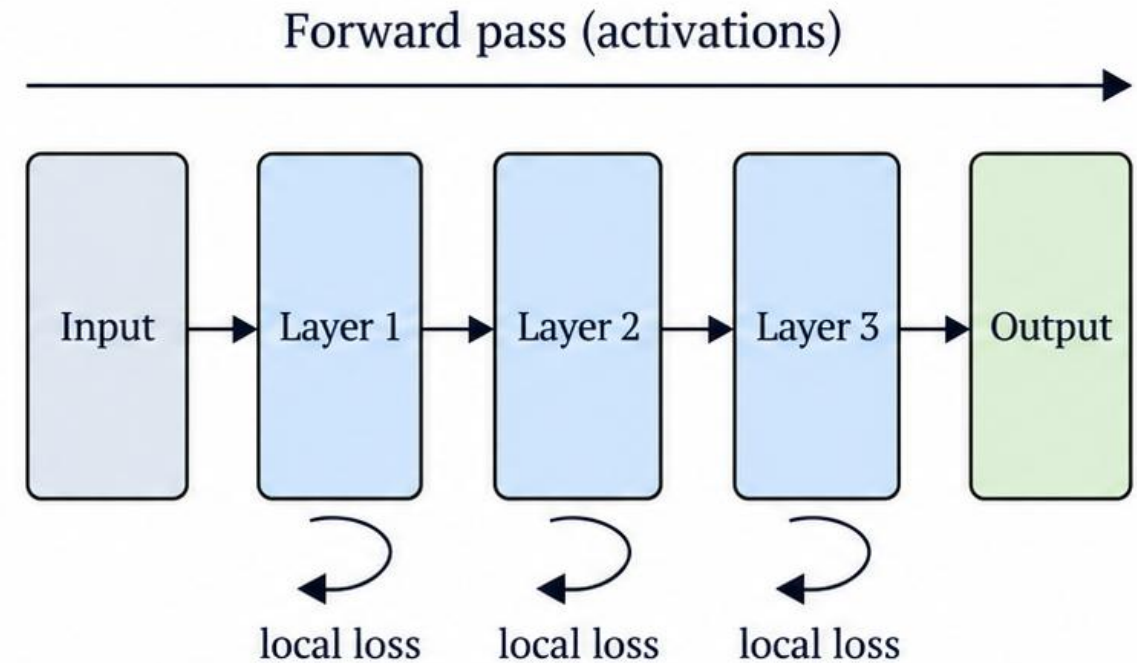
Membrane Potential



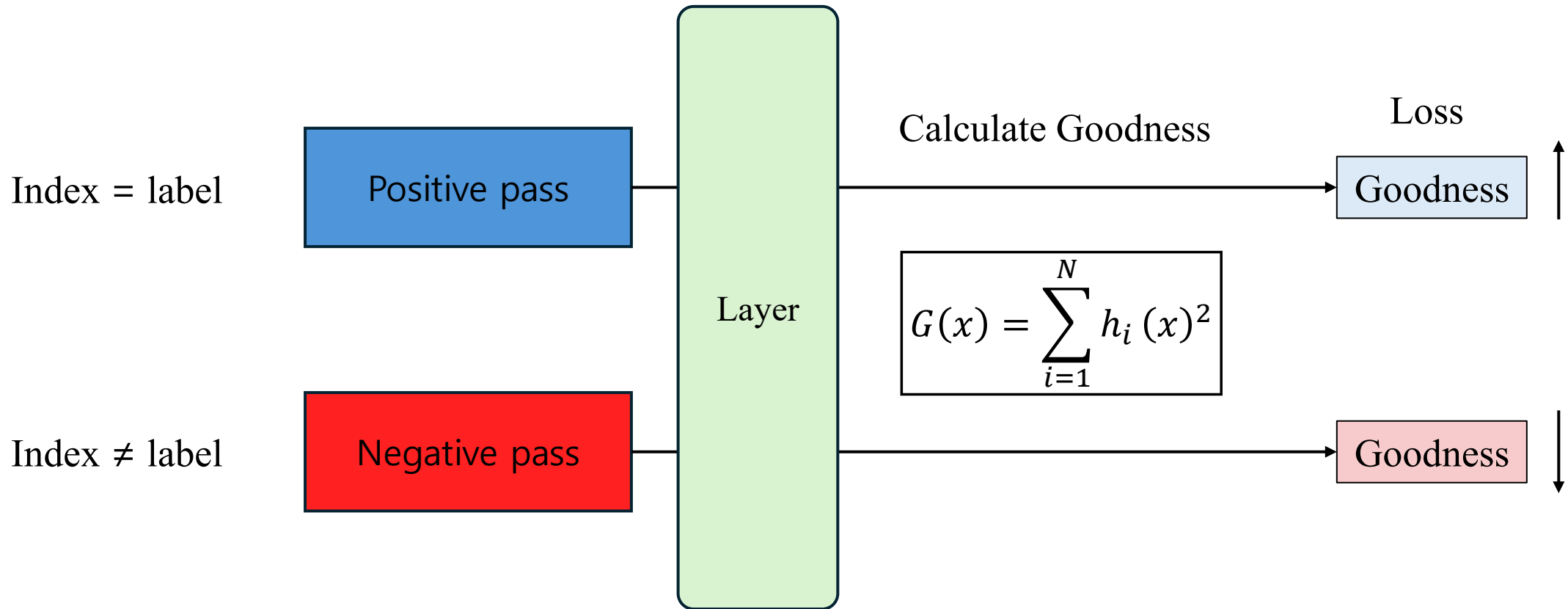
1) Backpropagation vs local learning



VS

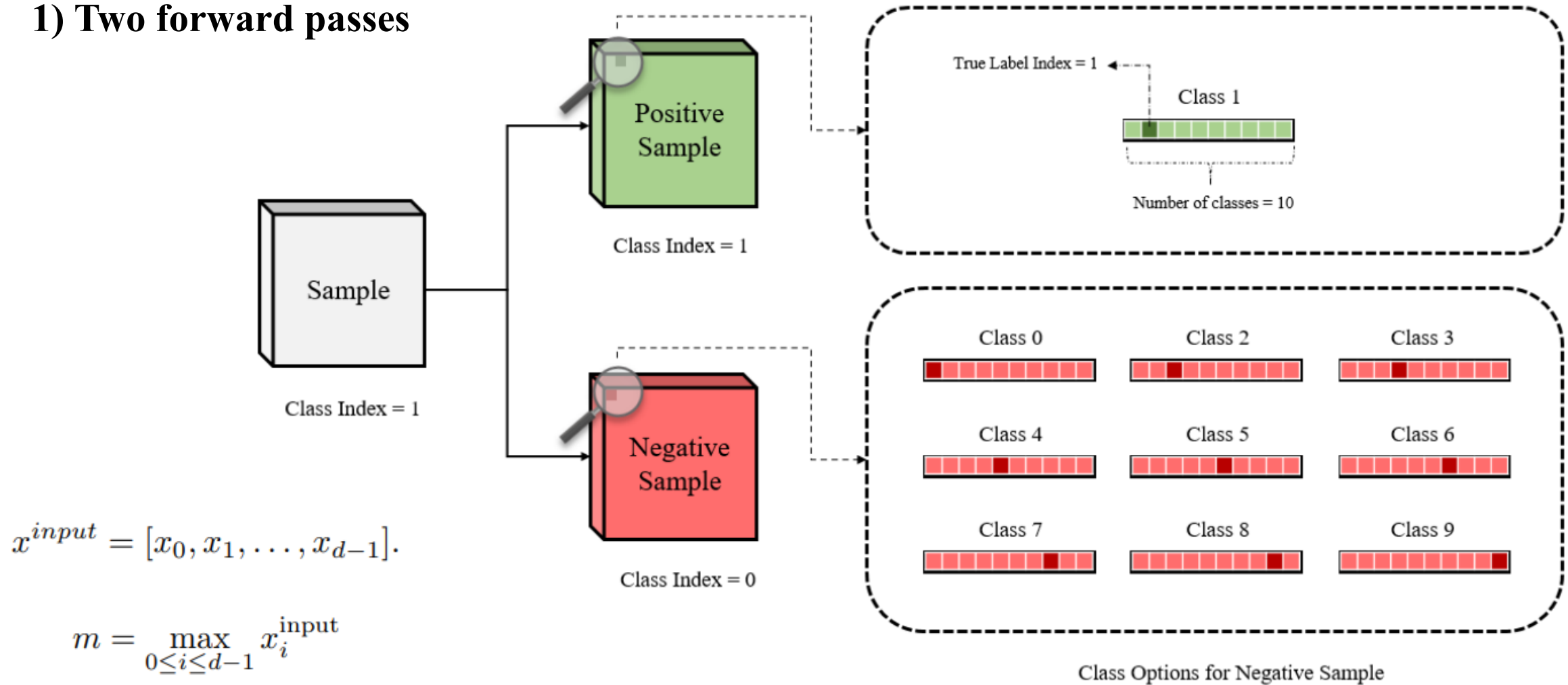


2) Two forward passes



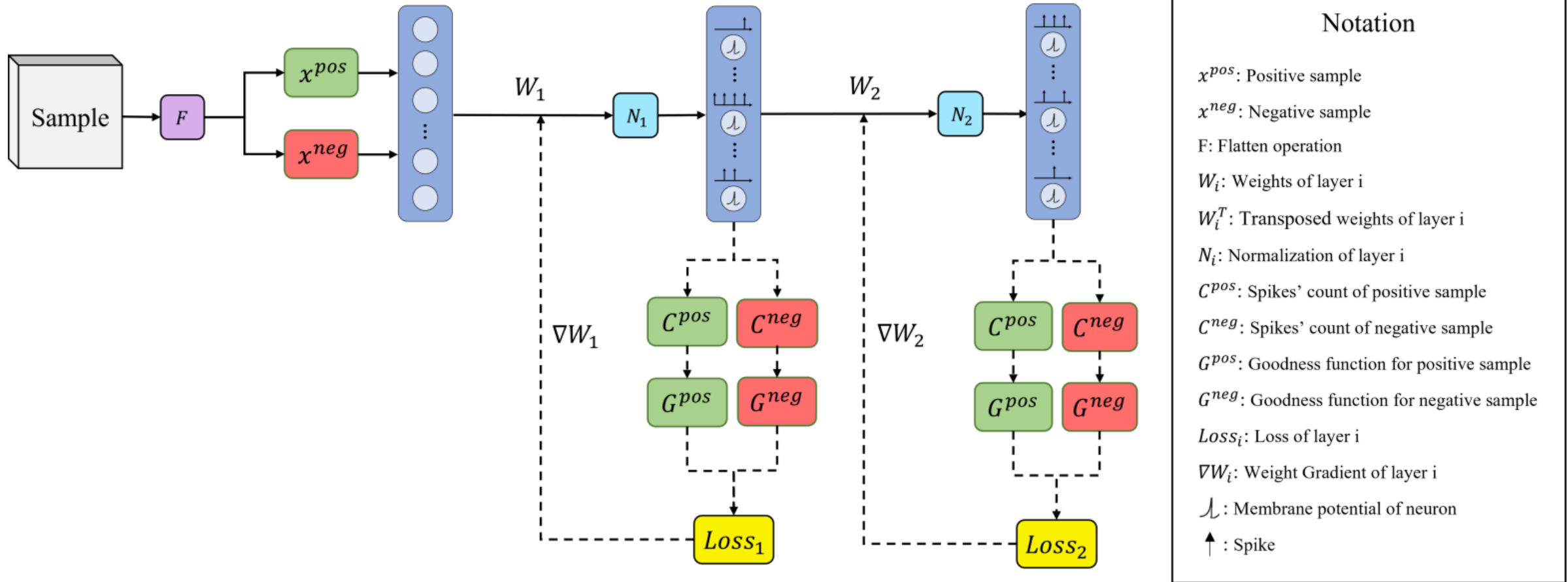
03 Forward-Forward in SNNs

1) Two forward passes



03 Forward-Forward in SNNs

1) Two forward passes



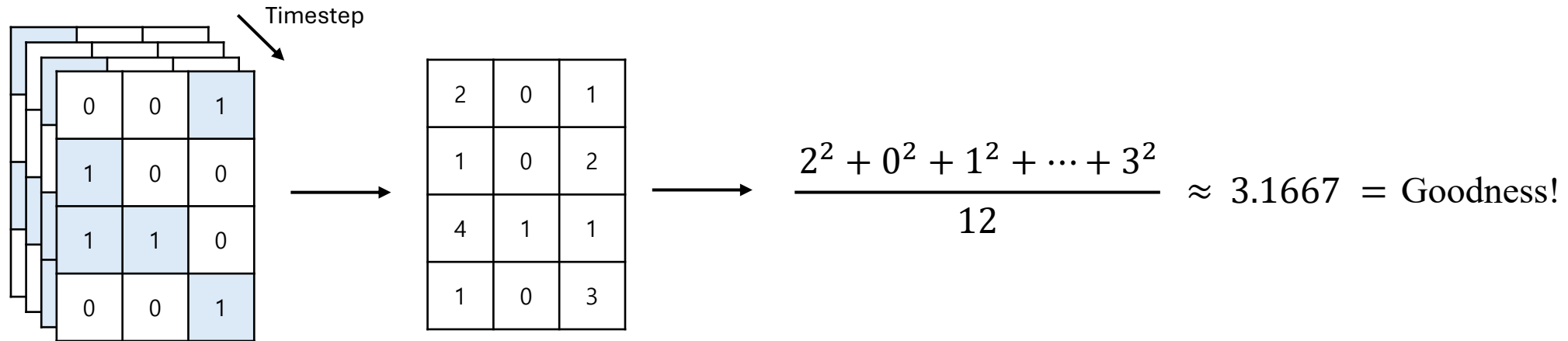
2) Calculate Loss

$$C_i^{pos} = \sum_{t=1}^T S_i^{pos}[t],$$

$$G^{pos} = \frac{1}{N} \sum_{i=1}^N (C_i^{pos})^2,$$

$$C_i^{neg} = \sum_{t=1}^T S_i^{neg}[t],$$

$$G^{neg} = \frac{1}{N} \sum_{i=1}^N (C_i^{neg})^2,$$

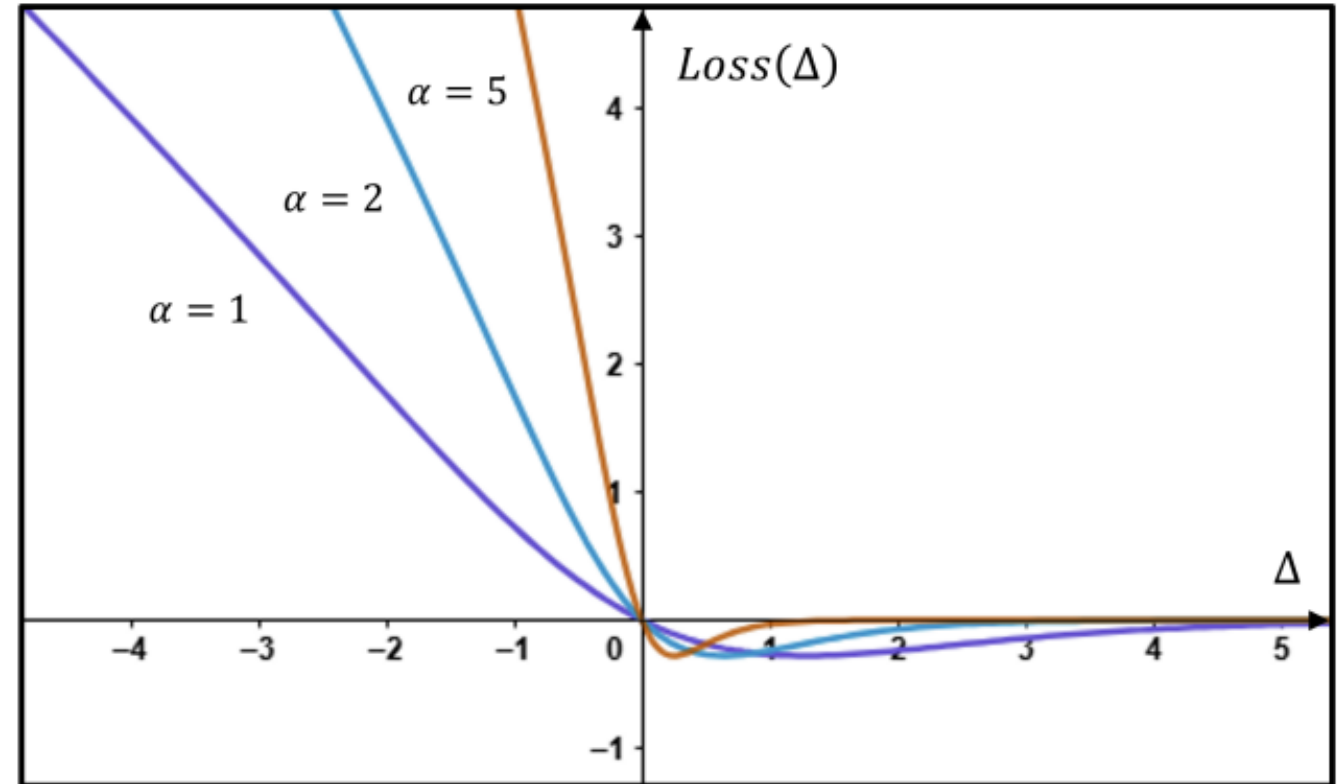


03 Forward-Forward in SNNs

2) Calculate Loss

$$\Delta = G^{\text{pos}} - G^{\text{neg}},$$

$$\text{Loss} = \frac{-\alpha\Delta}{1 + e^{\alpha\Delta}},$$



1) Comparison with SNNs

Dataset	Model	Architecture	Neuron model	Learning Approach	Accuracy (%)
MNIST	Proposed model	784-500-500	LIF ^{β}	FF	98.34
	Ororbias. [27]	784-7000-7000	LIF	FF	97.46
	Terres et al. [28]	784-1400-1400	LIF	FF	93.27
	Taylor et al. [41] [†]	784-1000-10	LIF ^{β}	BP	97.91
	Comsa et al. [40]	784-340-10	IF (alpha-PSP)	BP	97.90
	Neftci et al. [4] [†]	784-1000-10	LIF ^{β}	BP	97.87
F-MNIST	Proposed model	784-500-500	LIF ^{β}	FF	89.36
	Terres et al. [28]	784-1400-1400	LIF	FF	85.68
	Neftci et al. [4] [†]	784-1000-10	LIF ^{β}	BP	89.93
	Taylor et al. [41] [†]	784-1000-10	LIF ^{β}	BP	89.05
	Zhang et al. [44] [†]	784-1000-10	IF(ReLU-PSP)	BP	88.1
	Kheradpisheh et al. [42] [†]	784-1000-10	IF	BP	88.0
	Perez-Nieves et al. [43]	784-200-10	LIF	BP	82.20
K-MNIST	Proposed model	784-500-500	LIF ^{β}	FF	91.26
	Ororbias. [27]	784-7000-7000	LIF	FF	91.14
	Terres et al. [28]	784-1400-1400	LIF	FF	85.91
N-MNIST	Proposed model	2312-500-500	LIF ^{β}	FF	97.26
	Neftci et al. [4]	2312-300-10	LIF ^{β}	BP	97.47
	Taylor et al. [41]	2312-300-10	LIF	BP	95.91
	Perez-Nieves et al. [43]	2312-200-10	LIF	BP	92.70
SHD	Proposed model	700-500-500	recurrent LIF	FF	77.87
	Cramer et al. [38]	700-128-20	recurrent LIF	BP	71.40
	Neftci et al. [4]	700-300-20	LIF ^{β}	BP	70.81
	Cramer et al. [38]	700-128-20	LIF	BP	48.1

04 Experiment & Results

2) Comparison with ANNs

Dataset	Model	Architecture	Network Type	Accuracy (%)
MNIST	Proposed model	784-2000-2000	SNN	98.69
	Ororbia et al. [48]	784-2000-2000	ANN	98.66
	Hinton [13]	784-2000-2000-2000-2000	ANN	98.63
	Gandhi et al. [47]	784-2000-2000-2000-2000	ANN	98.63
	Aminifar et al. [51]	784-2000-2000-2000-2000	ANN	98.60
	Ghader et al. [52]	784-500-500	ANN	98.58
	Lee et al. [50]	784-2000-2000-2000	ANN	98.58
	Brenig et al. [46]	784-2000-2000-2000-2000	ANN	98.03
	Tang. [45]	784-200-200-200-50-50	ANN	98.00
	Tosato et al. [49]	784-784-784-784	ANN	94.00
F-MNIST	Proposed model	784-2000-2000	SNN	90.27
	Ghader et al. [52]	784-500-500-500	ANN	90.22
	Ororbia et al. [48]	784-2000-2000	ANN	89.60
	Brenig et al. [46]	784-2000-2000-2000-2000	ANN	87.31
	Tosato et al. [49]	784-784-784-784	ANN	82.60
CIFAR-10	Proposed model	3072-2000-2000	SNN	54.03
	Aminifar et al. [51]	3072-2000-2000-2000-2000	ANN	53.95
	Ghader et al. [52]	3072-500-500-500	ANN	53.31
	Brenig et al. [46]	3072-2000-2000-2000-2000	ANN	47.60

SNN + Local learning model

- **Limitations**

- ✓ Increased inference cost
- ✓ Architectural constraints
- ✓ Lack of timestep awareness

- **Future Directions**

- ✓ Minimize class-dependent inference cost
- ✓ Explore transformer compatibility
- ✓ Leverage SNN-specific characteristics



Thank You



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