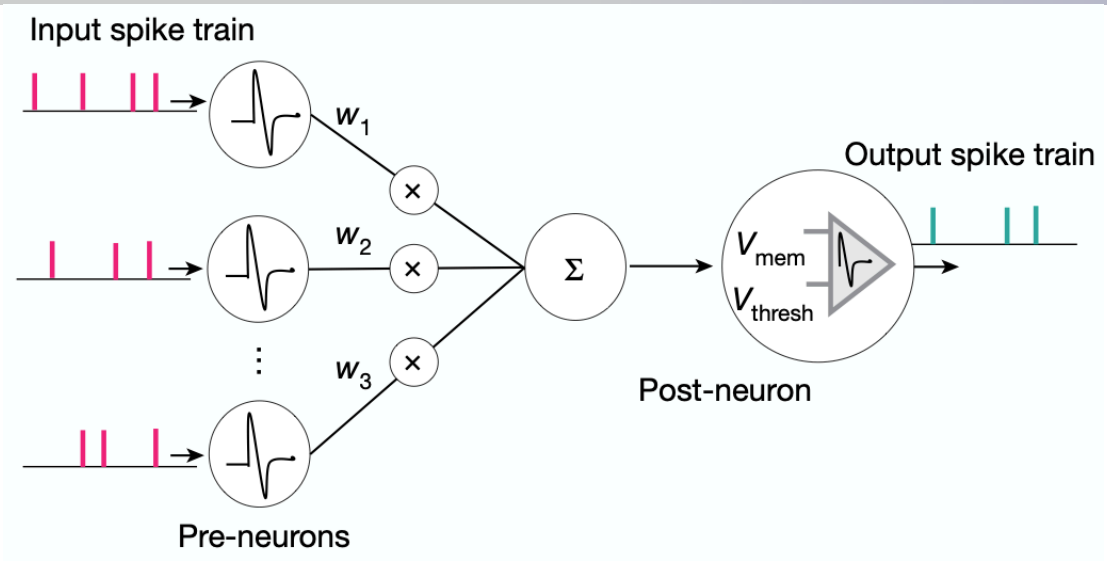
GLIF: A Unified Gated Leaky Integrate-and-Fire Neuron for Spiking Neural Networks

Xingting Yao[1,2], **Fanrong Li**[1,2], **Zitao Mo**[1], **Jian Cheng**[1,3*]
[1]Institute of Automation, Chinese Academy of Sciences
[2]School of Future Technology, University of Chinese Academy of Sciences
[3]CAS Center for Excellence in Brain Science and Intelligence Technology
{yaoxingting2020, lifanrong2017, mozitao2017, jian.cheng}@ia.ac.cn,

*Corresponding author

Introduction

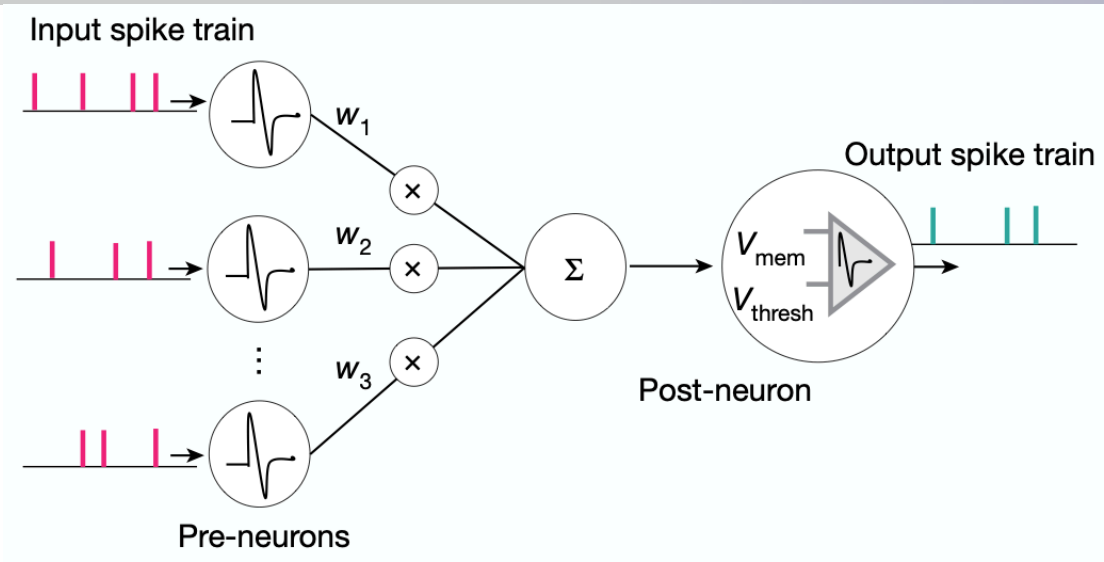
- **Leaky Integrate-and-Fire Model**
  - **LIF Model is commonly adopted to model a spiking neuron in spiking neural networks (SNNs).**



✤ [Roy K, Jaiswal A, Panda P.]

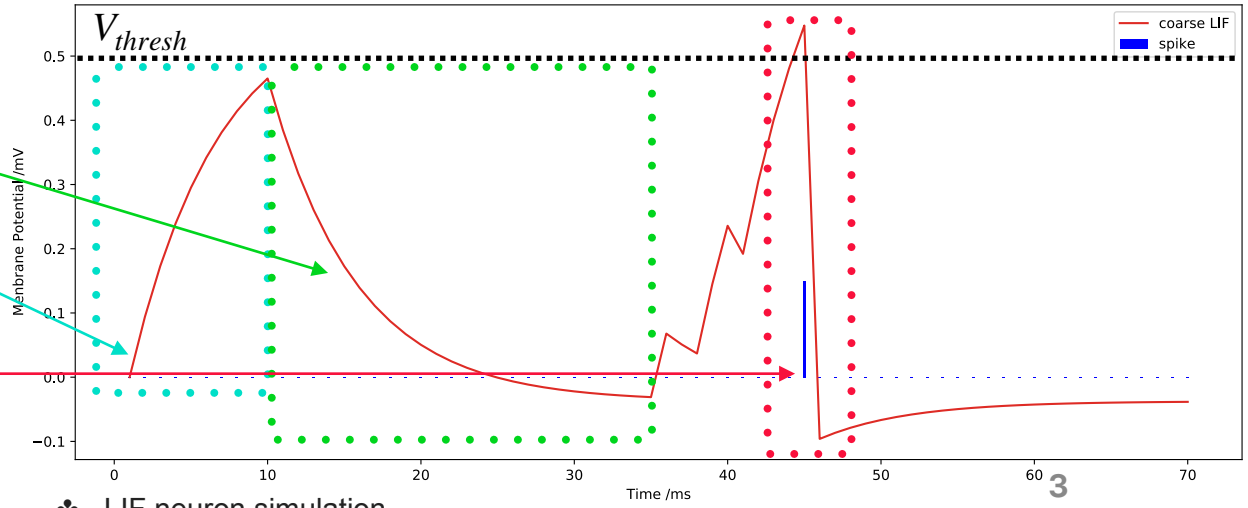
Introduction

- **Leaky Integrate-and-Fire Model**
  - **LIF Model is commonly adopted to model a spiking neuron in spiking neural networks (SNNs).**



✤ [Roy K, Jaiswal A, Panda P.]

- **Three basic bio-behaviors:**
  - Leak: membrane potential leakage
  - Integrate: integration accumulation
  - **Fire**: spike initiation



✤ LIF neuron simulation

Motivation

- **Super Neuron———GLIF**
  - **Variant LIF models with different bio-features are proposed in prior arts. No work proposes a clear study on how to unify and leverage these different bio-features.**
  - **Could the higher neuronal dynamic diversity of spiking neurons help SNNs do better?**

Bio-behavior	Feasible Bio-features	
Leak	Exponential	Linear
Integrate	Uniform-coding	Flexible-coding
Fire	Hard-reset	Soft-reset

Methodology

- **Revisiting**
  - **Vanilla LIF:**

$$\mathbf{U}^{(t,l)} = \tau_{exp}\mathbf{U}^{(t-1,l)} \odot (1 - \mathbf{S}^{(t-1,l)}) + \mathbf{C}^{(t,l)},$$
$$\mathbf{C}^{(t,l)} = \mathbf{W} \cdot \mathbf{S}^{(t,l-1)},$$
$$\mathbf{S}^{(t,l)} = \mathbb{H}(\mathbf{U}^{(t,l)} - V_{th})$$

  - **Constants or parameters are primitives**

  - **Choosing different primitives:**

$$\mathbf{U}^{(t,l)} = \mathbf{U}^{(t-1,l)} \odot (1 - \mathbf{S}^{(t-1,l)}) + \mathbf{C}^{(t,l)} - \tau_{lin}$$

Methodology

- **Gated LIF**
  - **LIF with both exponential and linear decay:**

$$\mathbf{U}^{(t,l)} = \tau_{exp}\mathbf{U}^{(t-1,l)} \odot (1 - \mathbf{S}^{(t-1,l)}) + \mathbf{C}^{(t,l)} - \tau_{lin},$$
$$\mathbf{C}^{(t,l)} = \mathbf{W} \cdot \mathbf{S}^{(t,l-1)},$$
$$\mathbf{S}^{(t,l)} = \mathbb{H}(\mathbf{U}^{(t,l)} - V_{th})$$

  - **Coarsely fused LIF:**

$$\mathbf{U}^{(t,l)} = \mathbf{L}^{(t,l)} + \mathbf{I}^{(t,l)} + \mathbf{F}^{(t,l)} \odot \mathbf{S}^{(t-1,l)},$$
$$\mathbf{C}^{(t,l)} = \mathbf{W} \cdot \mathbf{S}^{(t,l-1)},$$
$$\mathbf{S}^{(t,l)} = \mathbb{H}(\mathbf{U}^{(t,l)} - V_{th}),$$
$$\mathbf{L}^{(t,l)} = \tau_{exp}\mathbf{U}^{(t-1,l)} - \tau_{lin},$$
$$\mathbf{I}^{(t,l)} = g^t\mathbf{C}^{(t,l)},$$
$$\mathbf{F}^{(t,l)} = -\tau_{exp}\mathbf{U}^{(t-1,l)} - V_{re},$$

Methodology

- **Gated LIF**
  - **Gated LIF with both exponential and linear decay:**

$$\mathbf{U}^{(t,l)} = [1 - \alpha(1 - \tau_{exp})]\mathbf{U}^{(t-1,l)} \odot (1 - \mathbf{S}^{(t-1,l)}) + \mathbf{C}^{(t,l)} - (1 - \alpha)\tau_{lin},$$

$$\mathbf{C}^{(t,l)} = \mathbf{W} \cdot \mathbf{S}^{(t,l-1)},$$

$$\mathbf{S}^{(t,l)} = \mathbb{H}(\mathbf{U}^{(t,l)} - V_{th})$$

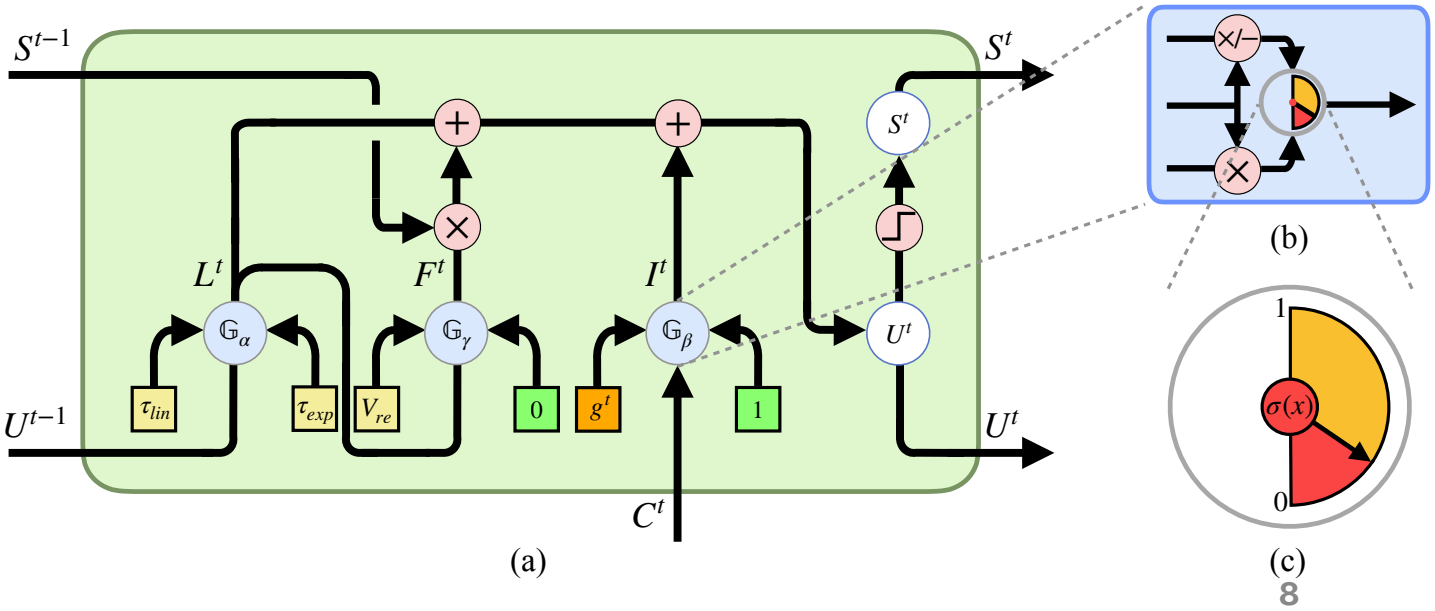
Methodology

- **Gated LIF**
  - **Gated LIF with both exponential and linear decay:**

$$\mathbf{U}^{(t,l)} = [1-\alpha(1-\tau_{exp})]\mathbf{U}^{(t-1,l)} \odot (1-\mathbf{S}^{(t-1,l)}) + \mathbf{C}^{(t,l)} - (1-\alpha)\tau_{lin},$$
$$\mathbf{C}^{(t,l)} = \mathbf{W} \cdot \mathbf{S}^{(t,l-1)},$$
$$\mathbf{S}^{(t,l)} = \mathbb{H}(\mathbf{U}^{(t,l)} - V_{th})$$

  - **GLIF formulation:**

$$\mathbf{U}^{(t,l)} = \mathbf{L}^{(t,l)} + \mathbf{I}^{(t,l)} + \mathbf{F}^{(t,l)} \odot \mathbf{S}^{(t-1,l)},$$
$$\mathbf{C}^{(t,l)} = \mathbf{W} \cdot \mathbf{S}^{(t,l-1)},$$
$$\mathbf{S}^{(t,l)} = \mathbb{H}(\mathbf{U}^{(t,l)} - V_{th}),$$
$$\mathbf{L}^{(t,l)} = [1-\alpha(1-\tau_{exp})]\mathbf{U}^{(t-1,l)} - (1-\alpha)\tau_{lin},$$
$$\mathbf{I}^{(t,l)} = [1-\beta(1-g^t)]\mathbf{C}^{(t,l)},$$
$$\mathbf{F}^{(t,l)} = -(0+\gamma)\mathbf{L}^{(t,l)}_{exp} - (1-\gamma)V_{re},$$



Methodology

- **Gated LIF**
  - **Channel-wise parametric method :**

Primitives

$$\tau_{lin} \quad \tau_{exp} \quad V_{re} \quad g^t$$

Gating factors

$$\alpha \qquad \beta \qquad \gamma$$

$$\alpha = \frac{1}{1 + \exp(-x_\alpha)}$$

Methodology

- **Gated LIF**
  - **Channel-wise parametric method :**

Primitives

$$\tau_{lin} \quad \tau_{exp} \quad V_{re} \quad g^t$$

Gating factors

$$\alpha \qquad \beta \qquad \gamma$$

$$\alpha = \frac{1}{1 + \exp(-x_\alpha)}$$

  - **Backpropagation through time (BPTT):**

$$\frac{d\mathbb{H}(x)}{dx} = \mathbb{H}(0.5 - |x|)\,.$$

Experiments

- **Comparisons with SOTAs**

Table 1: Comparisons with existing works on CIFAR datasets.

Method	Architecture	CIFAR10		CIFAR100	
		TimeStep	Accuracy	TimeStep	Accuracy
STBP[42]	CIFARNet	12	89.83	-	-
STBP NeuNorm[8]	CIFARNet	12	90.53	-	-
TSSL-BP[50]	CIFARNet	5	91.41	-	-
STBP-tdBN[9]	ResNet-19	6	93.16	6	71.12±0.57
		4	92.92	4	70.86±0.22
		2	92.34	2	69.41±0.08
TET[12]	ResNet-19	6	94.50±0.07	6	74.72±0.28
		4	94.44±0.08	4	74.47±0.15
		2	94.16±0.03	2	72.87±0.10
Dspike[11]	ResNet-18*	6	94.25±0.07	6	74.24±0.10
		4	93.66±0.05	4	73.35±0.14
		2	93.13±0.07	2	71.68±0.12
GLIF	CIFARNet	5	93.28	-	-
	ResNet-19	6	**95.03±0.08**	6	**77.35±0.07**
		4	**94.85±0.07**	4	**77.05±0.14**
		2	**94.44±0.10**	2	**75.48±0.08**
	ResNet-18	6	**94.88±0.15**	6	**77.28±0.14**
		4	**94.67±0.05**	4	**76.42±0.06**
		2	**94.15±0.04**	2	**74.60±0.24**

* denotes a highly handcrafted network.

Table 2: Comparisons on ImageNet.

Method	Architecture	T	Acc.
TET[12]	ResNet-34	6	64.79
Dspike[11]	ResNet-34	6	68.19
STBP-tdBN[9]	ResNet-34	6	63.72
SEW+PLIF[43]	SEW-ResNet-34	4	67.04
MS-ResNet[44]	MS-ResNet-18	6	63.10
GLIF	ResNet-34	6	**69.09**
	ResNet-34	4	**67.52**
	MS-ResNet-18	6	**68.11**

T denotes the time step.

Table 3: Comparisons on CIFAR10-DVS.

Method	Architecture	T	Acc.
STBP-tdBN[9]	ResNet-19	40	67.80
LIAF[28]	LIAF-Net	10	70.40
LIAF+TA[33]	TA-SNN-Net	10	72.00
PLIF[10]	PLIF-Net	20	74.80
SEW+PLIF[43]	7B-wideNet	16	74.40
GLIF	7B-wideNet	16	**76.80**

T denotes the time step.

Experiments

- **Ablation study**

Table 4: Comparisons with different simplex LIFs.

Model	000	001	010	011	100	101	110	111	GLIF
ResNet-19	76.29	76.59	73.89	74.71	77.15	76.26	74.39	74.68	**77.22**
ResNet-18	75.77	76.05	74.27	74.59	75.54	75.51	73.36	74.49	**76.39**

Table 5: Ablation study of gating factors.

Model	T	GLIF_s	GLIF_f	GLIF
ResNet-19	4	76.89	71.26	**77.22**
	2	75.27	72.14	**75.54**
ResNet-18	4	76.22	72.60	**76.39**
	2	74.24	72.10	**74.85**

T denotes the time step.

Table 6: Comparisons with Layer-wise GLIF.

Model	T	Layer-Wise	GLIF
ResNet-19	4	75.71	**77.22**
	2	74.19	**75.54**
ResNet-18	4	75.29	**76.39**
	2	73.40	**74.85**

T denotes the time step.


Thanks for Your Attendance !