

# Multi-Timescale Conductance (MTC) Spiking Networks

A Sparse, Gradient-Trainable Framework with  
Rich Firing Dynamics for Enhanced Temporal  
Processing

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# Team



**Àlex Fullea**  
**PhD Student**  
 Implementation  
 & Experiments



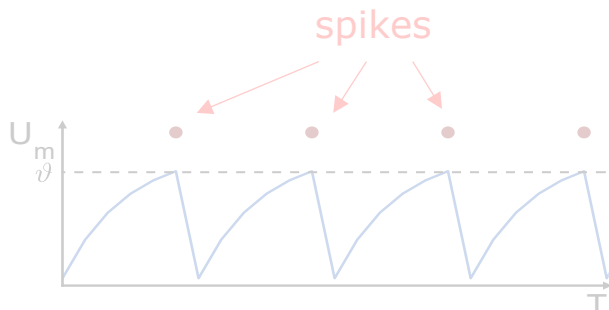
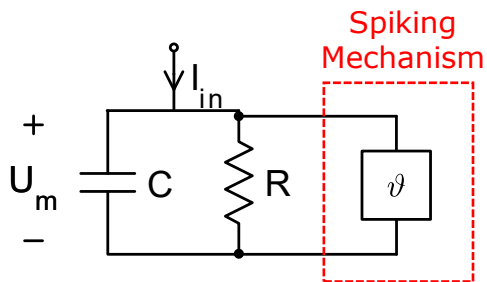
**Saray Soldado-Magraner**  
**Senior external co-author**  
 Concept & Methods,  
 Co-supervision



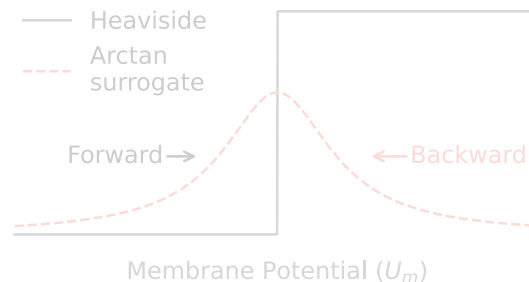
**Josep M. Margarit-Taulé**  
**Principal Investigator**  
 Concept & Methods,  
 Supervision & Funding

# The Cost of Oversimplification

✓ Simple → Efficient



✗ Surrogate grad. → Approximation



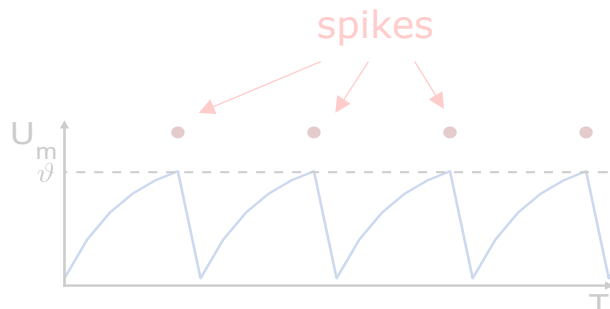
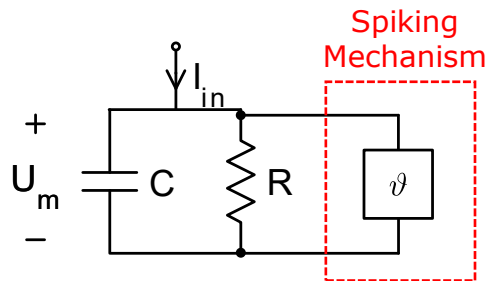
✗ Simple Spiking

↳ Poor Encoding

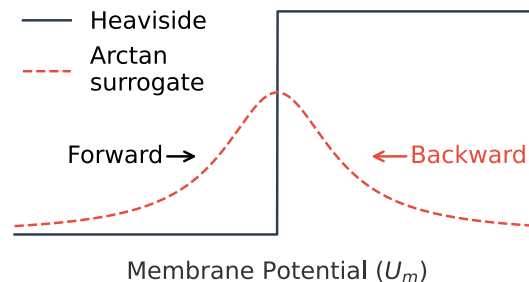
↳ Complex Network

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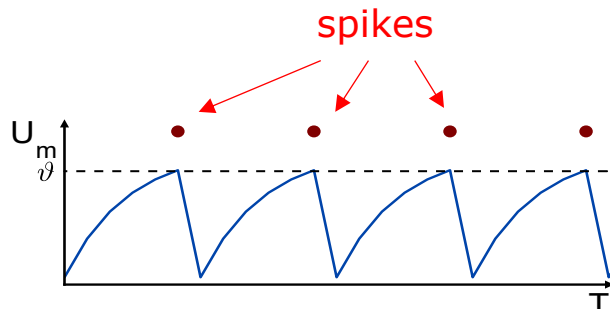
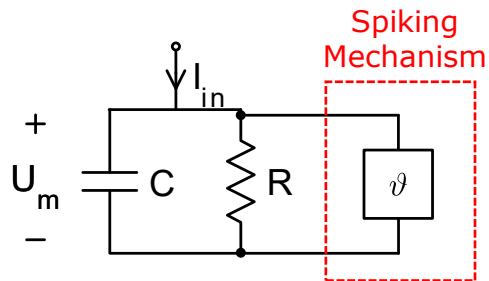
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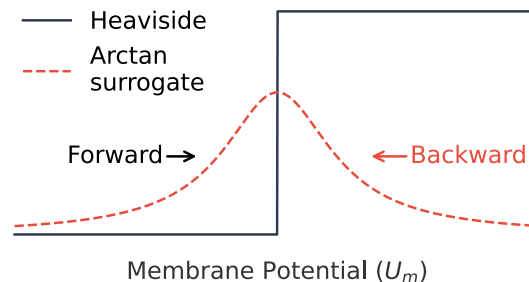
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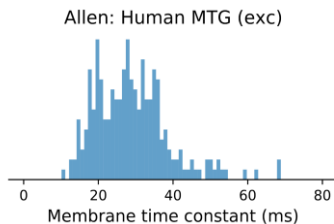
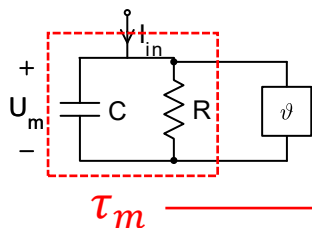


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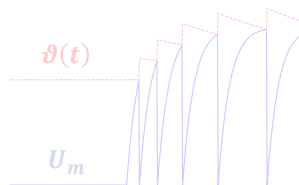
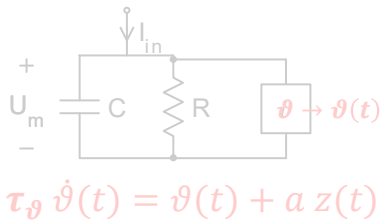
↳ Complex Network

# Towards Biologically-expressive SNNs



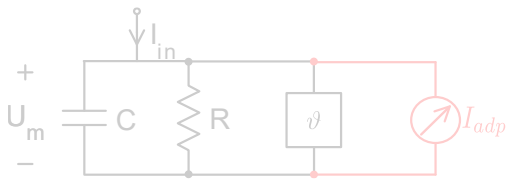
- Time-constant heterogeneity**

[Perez-Nieves et al., 2021]

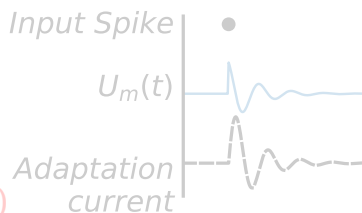


- Threshold adaptation**

[Bellec et al., 2018; Salaj et al., 2021]



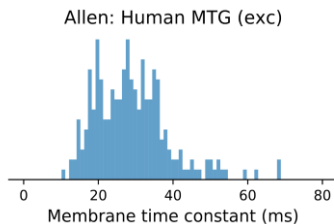
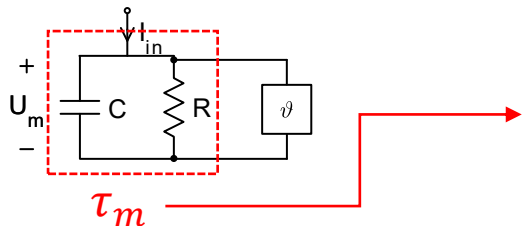
$$\tau_{adp} \dot{I}_{adp}(t) = -I_{adp}(t) + a U_m(t) + b z(t)$$



- Current Adaptation Dynamics**

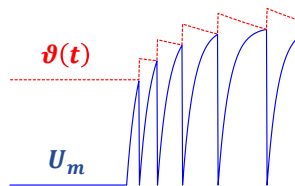
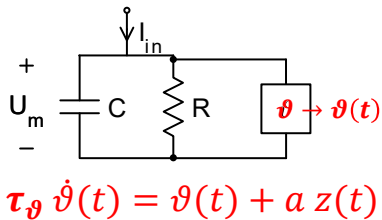
[Baronig et al., 2025]

# Towards Biologically-expressive SNNs



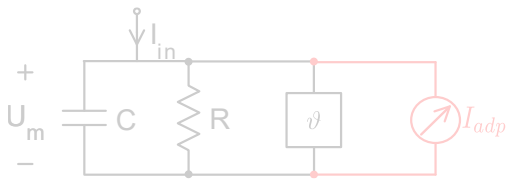
- **Time-constant heterogeneity**

[Perez-Nieves et al., 2021]

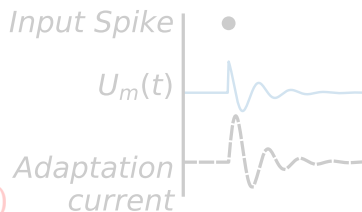


- **Threshold adaptation**

[Bellec et al., 2018; Salaj et al., 2021]



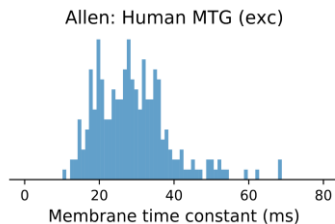
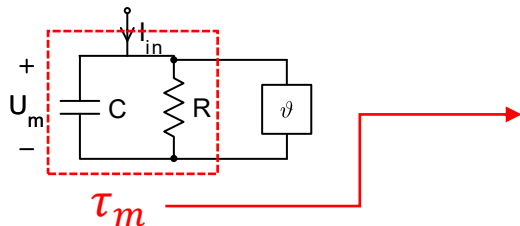
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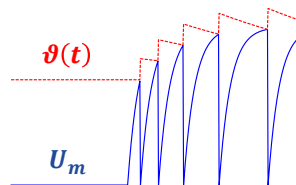
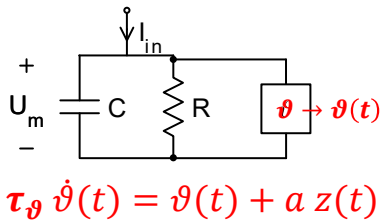
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# Towards Biologically-expressive SNNs



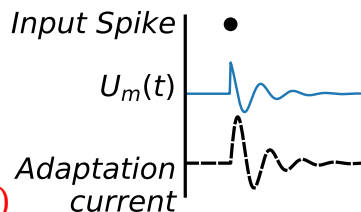
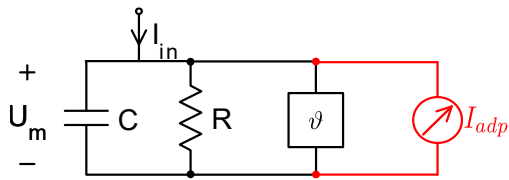
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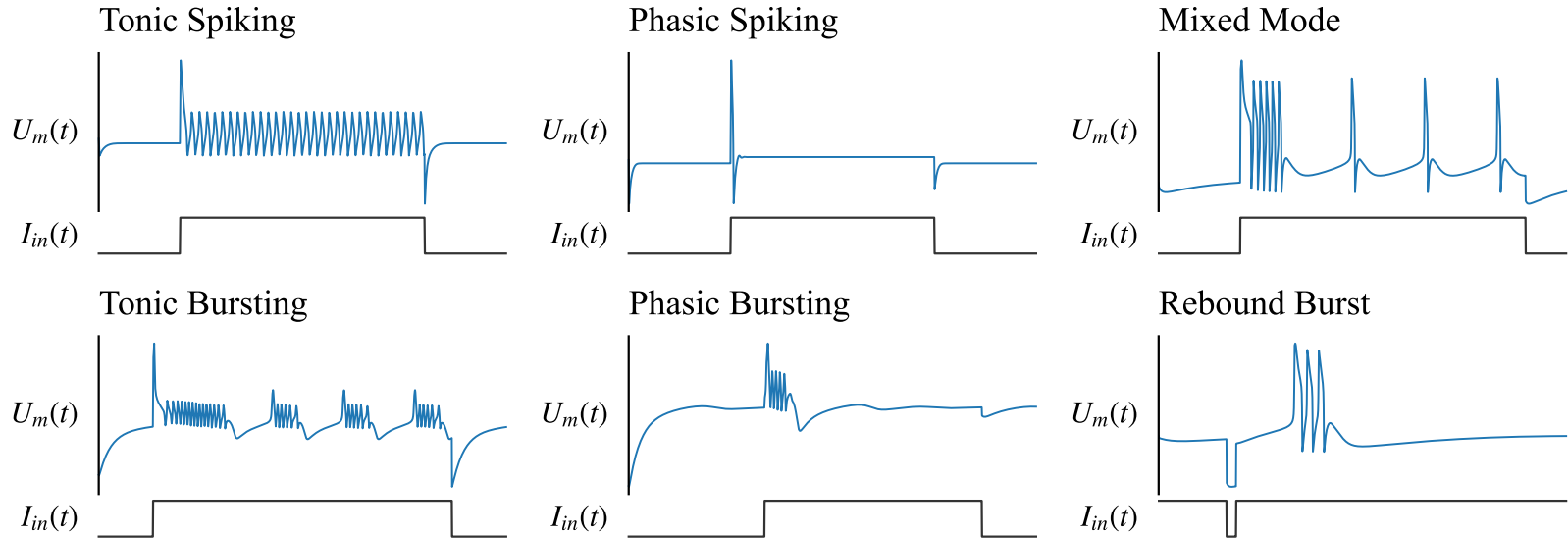
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- **Current Adaptation Dynamics**

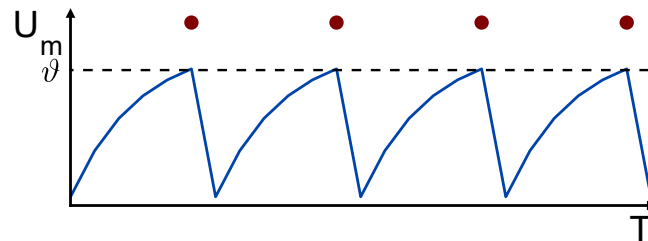
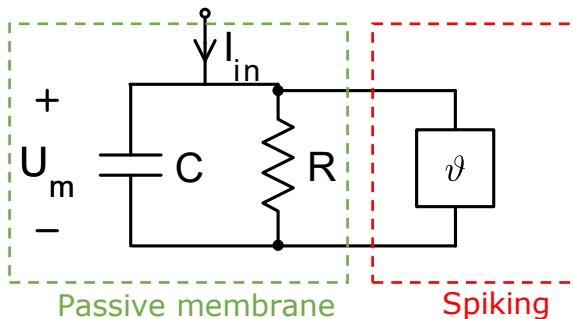
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# Richness of Biological Dynamics

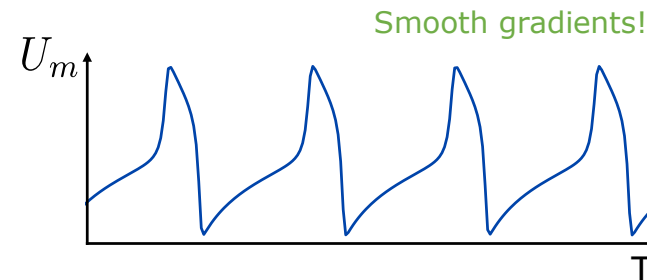
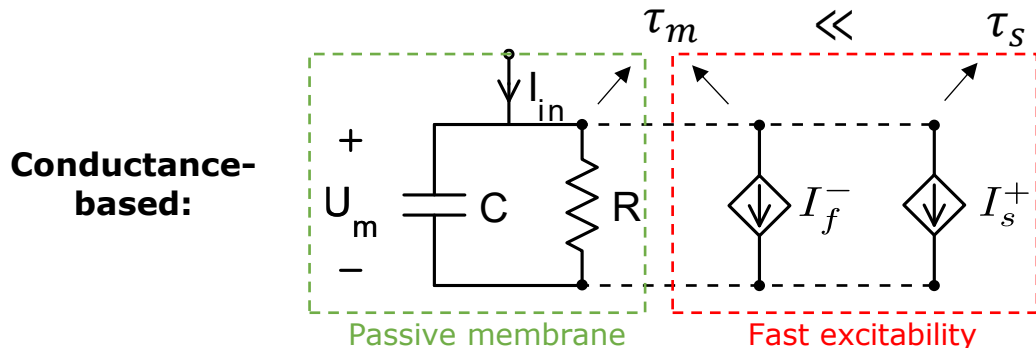
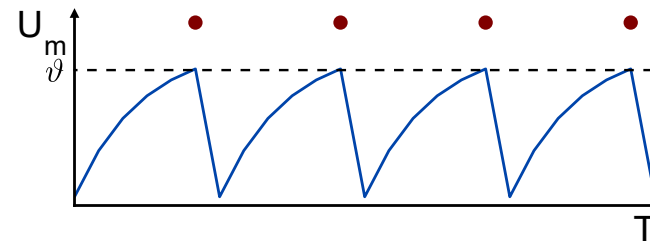
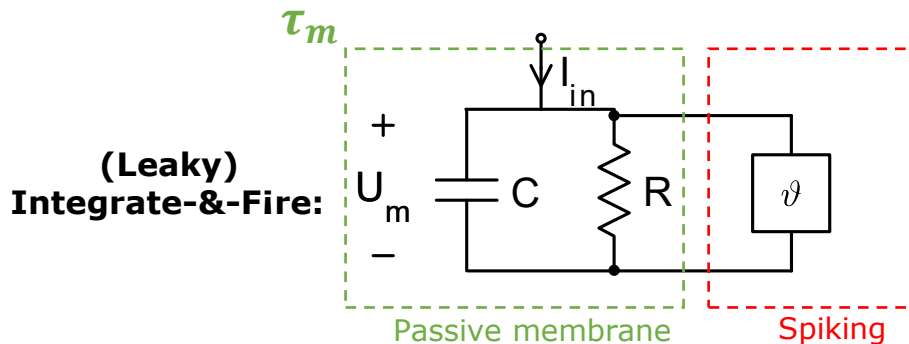


# Building the MTC Network

**(Leaky)  
Integrate-&-Fire:**



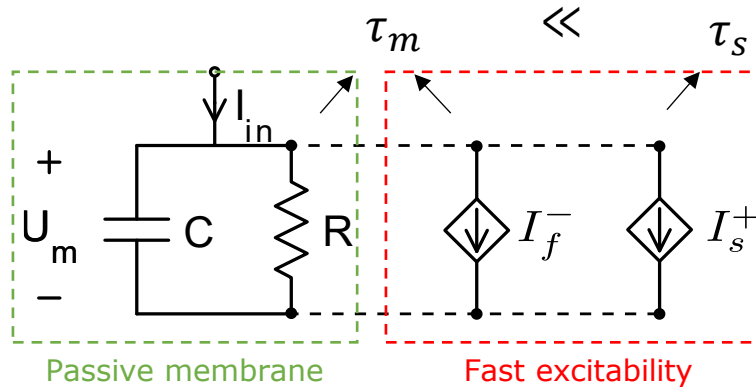
# Building the MTC Network



[Ribar and Sepulchre, 2019]

# Building the MTC Network

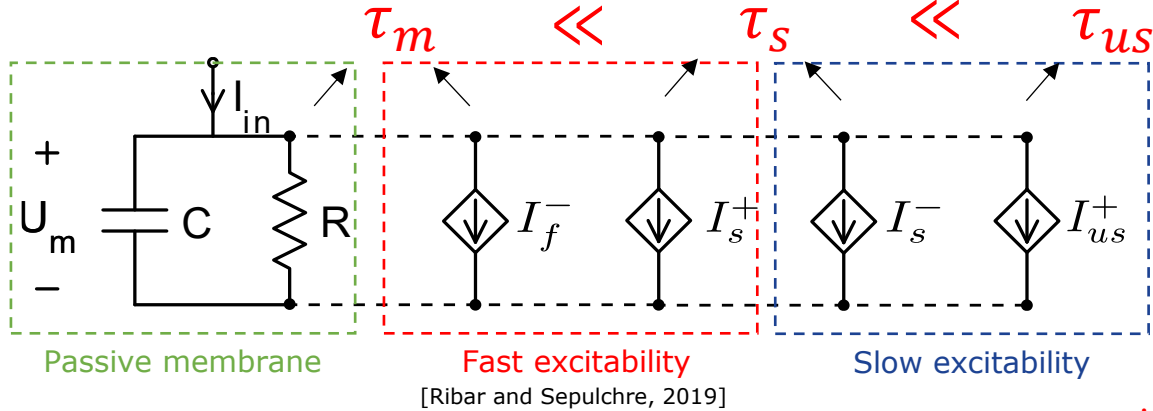
Conductance-based:



[Ribar and Sepulchre, 2019]

# Building the MTC Network

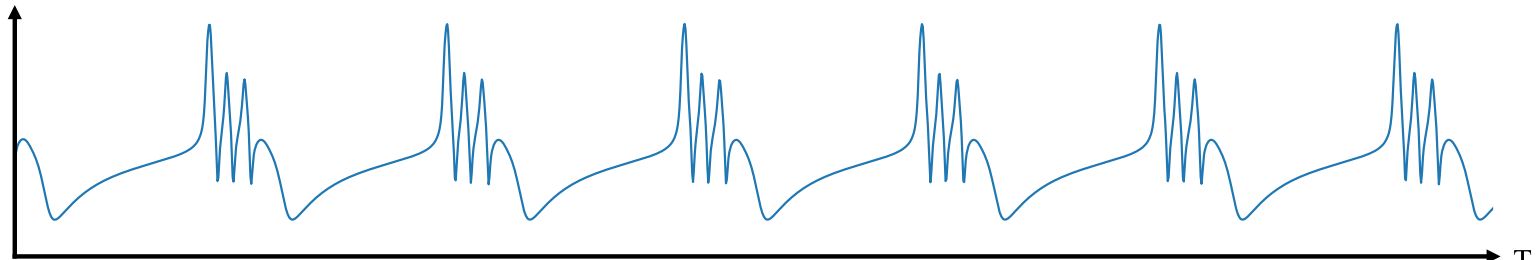
Conductance-based:



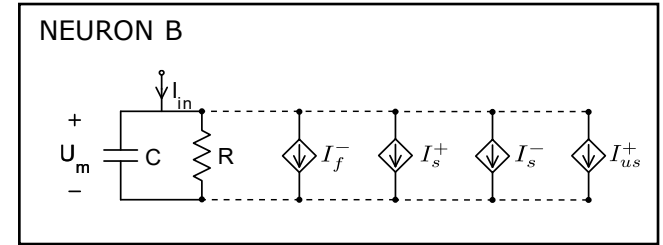
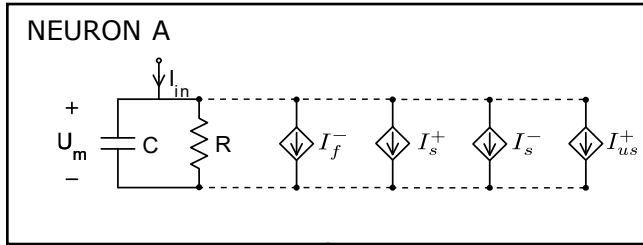
$$\tau_x \dot{U}_x(t) = -U_x(t) + U_m(t)$$

$$I_x^\pm(t) = \pm \alpha^\pm \tanh(U_x(t) - \delta_x^\pm)$$

Smooth gradients!

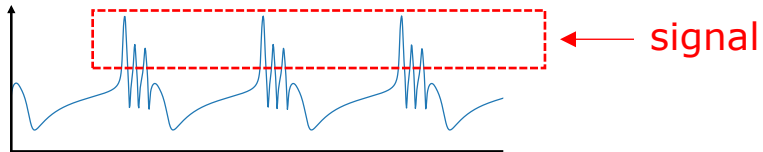


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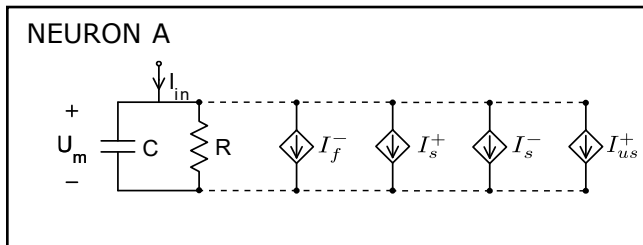


$W_{AB}$

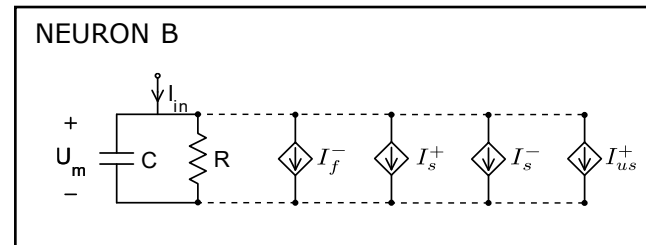
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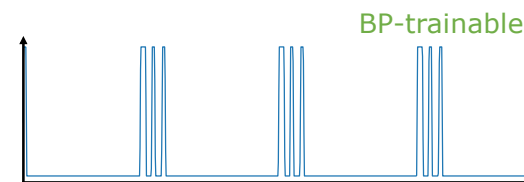
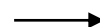
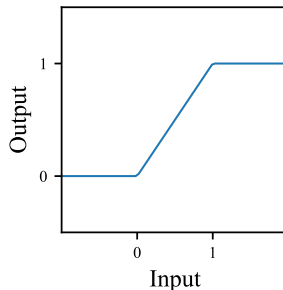


- ✓ Sparse Communication
- ✓ Amplitude Standardization
- ✓ Gradient-Friendly Landscape



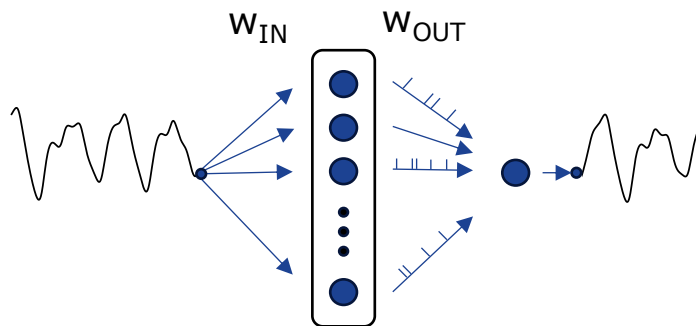
$W_{AB}$

Saturated ReLU Activation Function



# MTC Implementation in paper

SINGLE-LAYER  
FEEDFORWARD



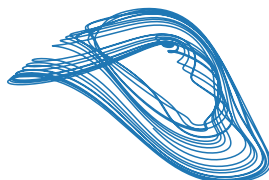
- 50% Spiking
- 50% Bursting



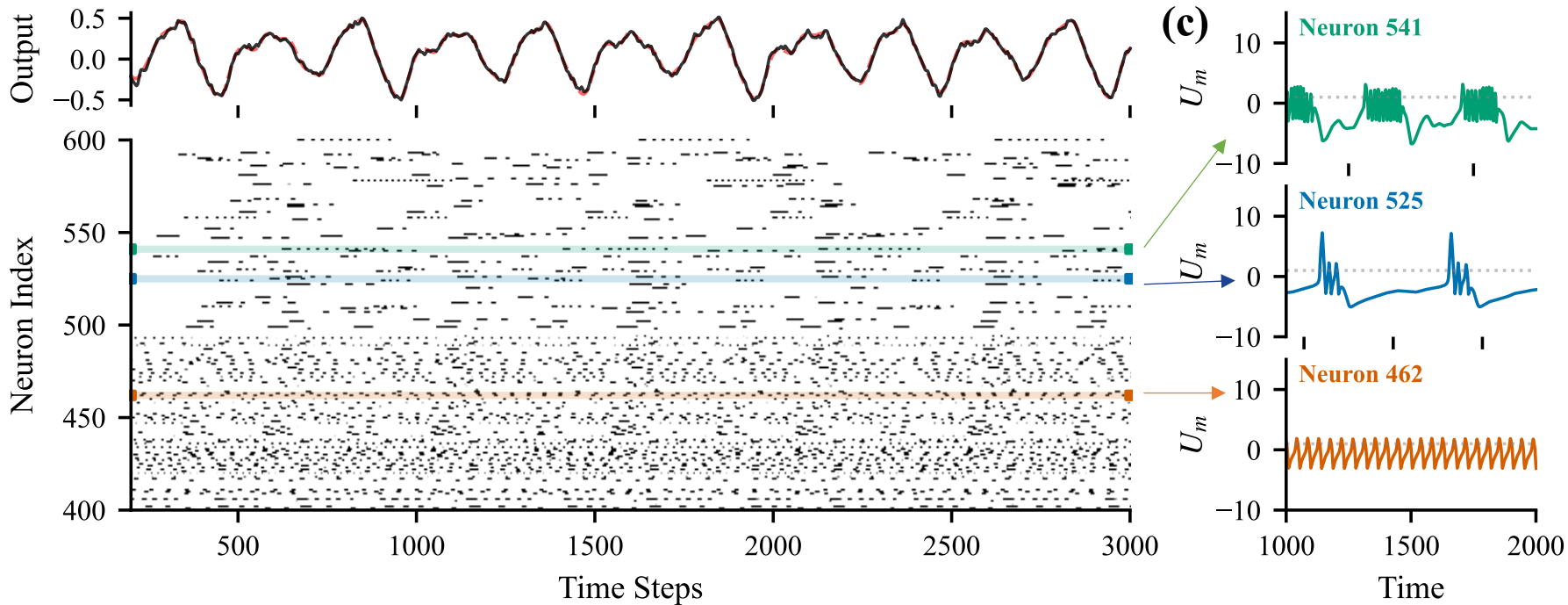
- Time-Constant heterogeneity

- Multi-Step ahead forecasting of a Chaotic Time-Series at the predictability horizon (Mackey-Glass)

Mackey-Glass Attractor



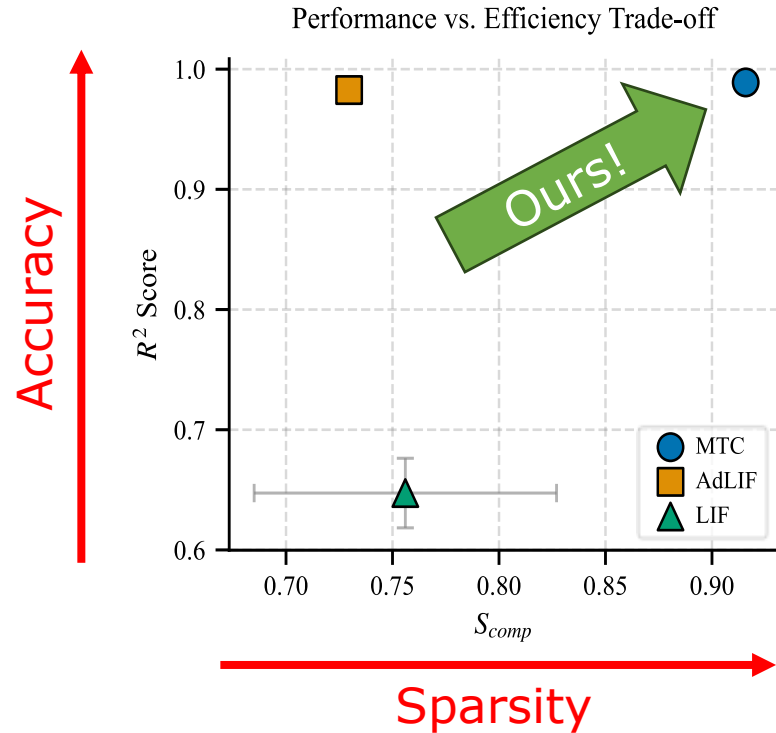
# Results



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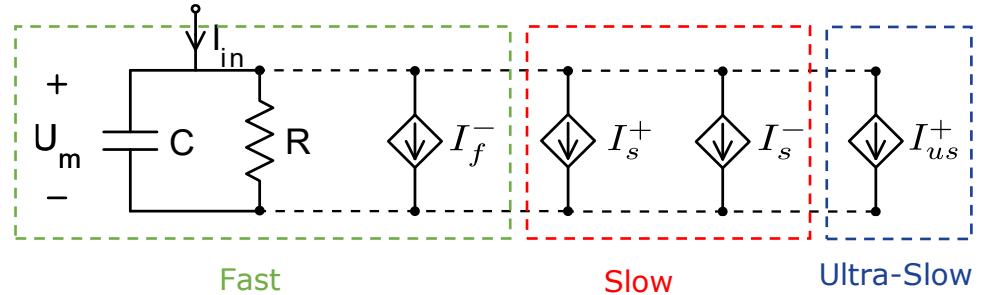
Model	$R^2$	$S_{comp}$
LIF	0,66	0,76
AdLIF	0,982	0,73
<b>MTC</b>	<b>0,988</b>	<b>0,92</b>

## LIF vs AdLIF vs MTC



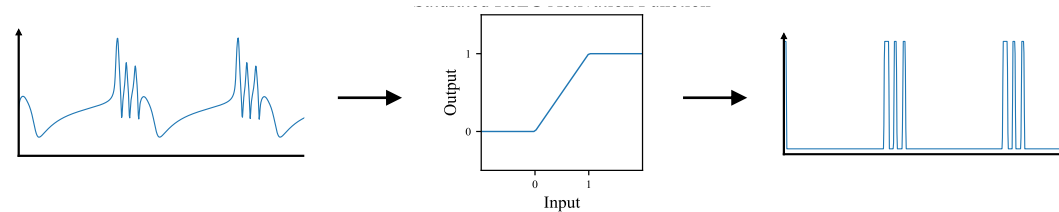
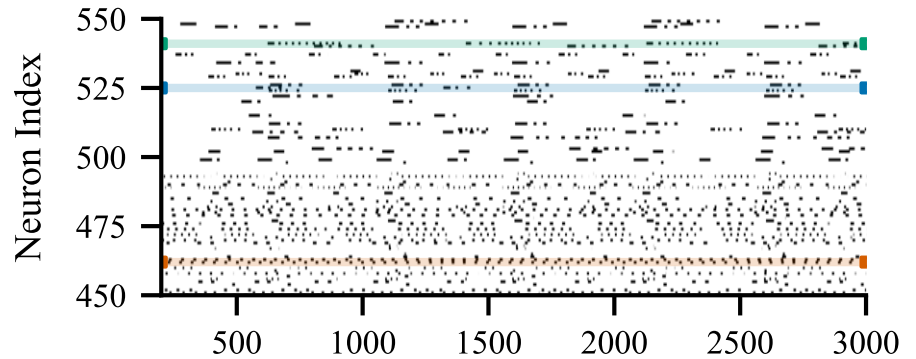
# Conclusions

- ✓ Conductance-base Network
- ✓ Multiple Timescales
- ✓ Rich Spiking Repertoire
- ✓ Directly differentiable
- ✓ Improved Accuracy
- ✓ Improved Sparsity



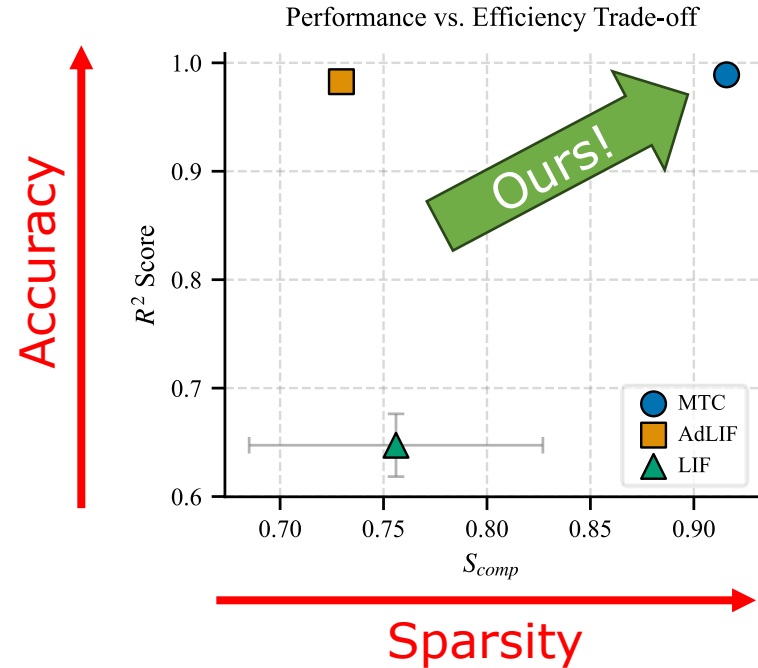
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*Thanks!*

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Josep Maria Margarit-Torres

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*Questions?*

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