LIÈGE université
Neuroengineering Laboratory

BOSA Federal Public Service Policy & Support

The Neuromorphic Control toolbox

44th Benelux Meeting on Systems and Control

Christian Fernandez Lorden Christian.FernandezLorden@uliege.be
Fulvio Forni
Guillaume Drion
Pierre Sacré
Alessio Franci

March 19, 2025

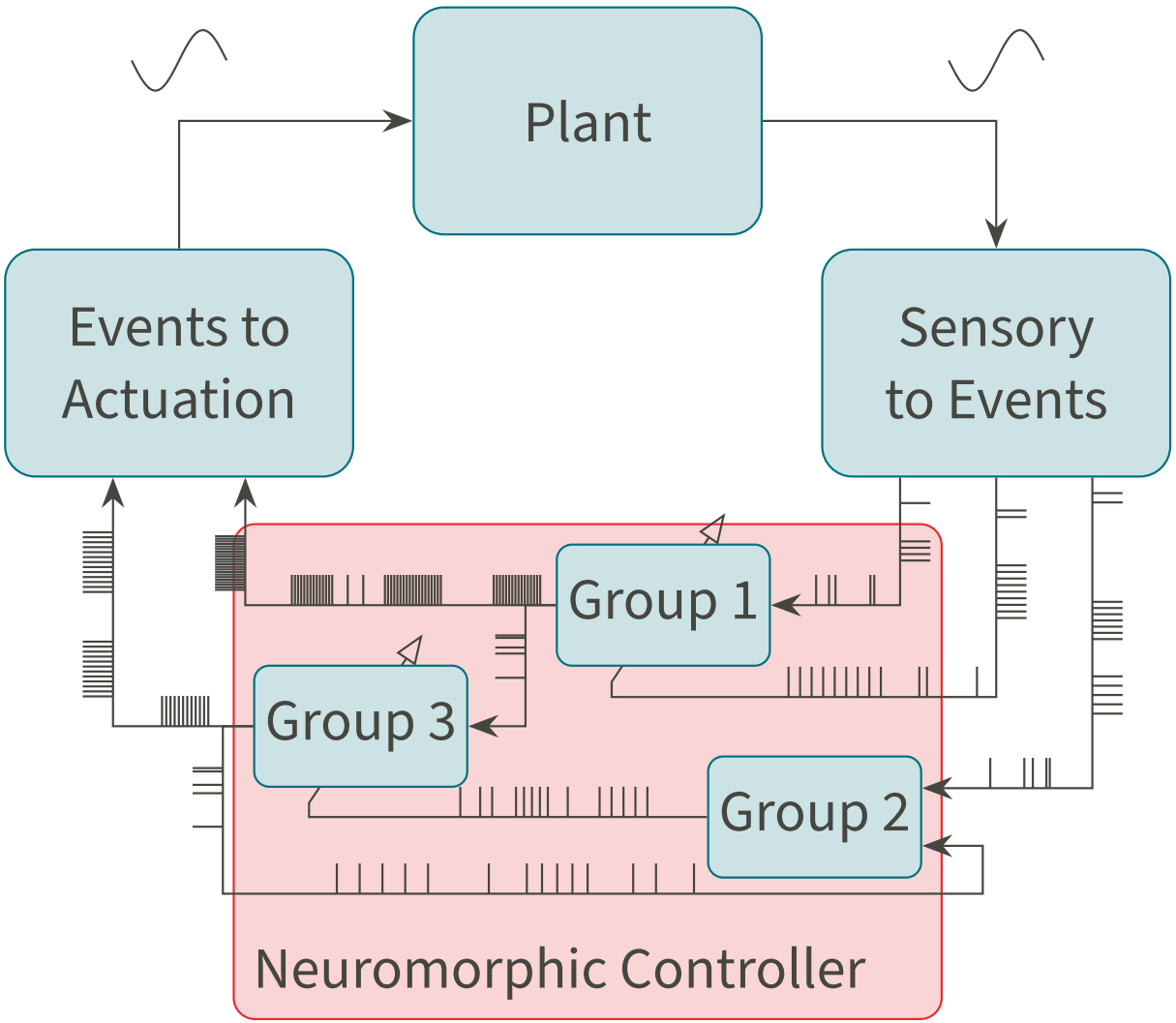
1. Introduction

2. Toolbox

3. Examples

4. Conclusion

What is Neuromorphic Control ?



Goal

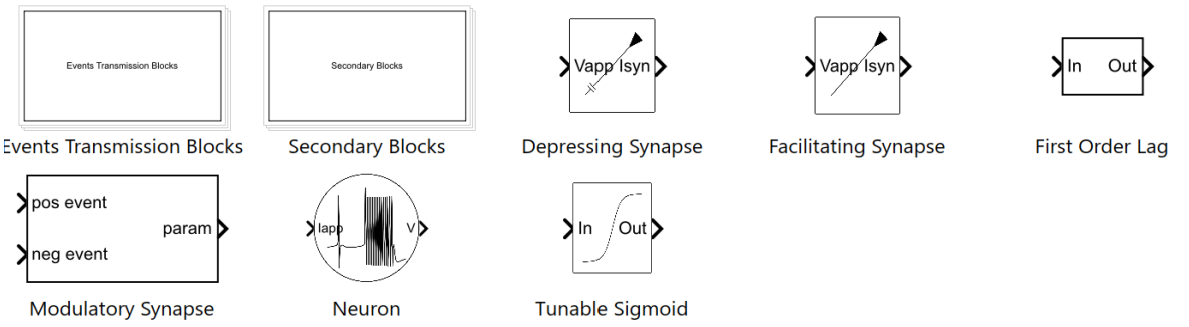
Control a plant with neuromorphic blocks.

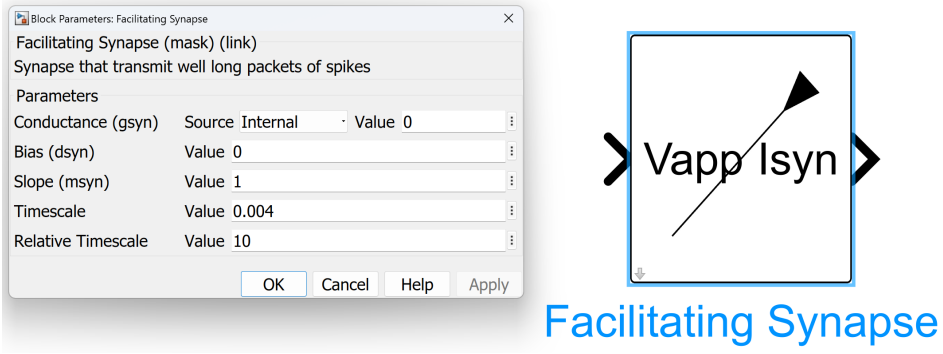
Key Points

- 1 bit Events
- Sparse Events
- Semantic Events

Inspired by Schmetterling et al. (2024) “Neuromorphic Control of a Pendulum”

Why the toolbox and What's inside ?





Why ?

- Quicker development
- Visual Representation
- Benefit from Simulink Libraries

1. Introduction

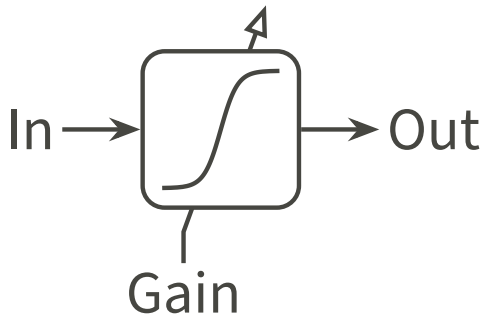
2. Toolbox

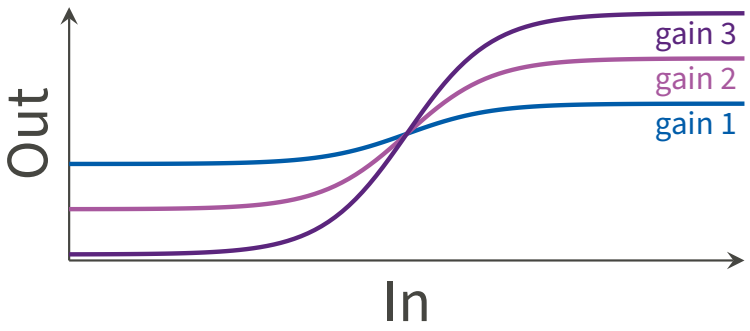
3. Examples

4. Conclusion

The Primitives : Two blocks are all you need

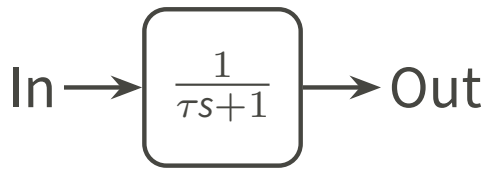
Tunable Saturation

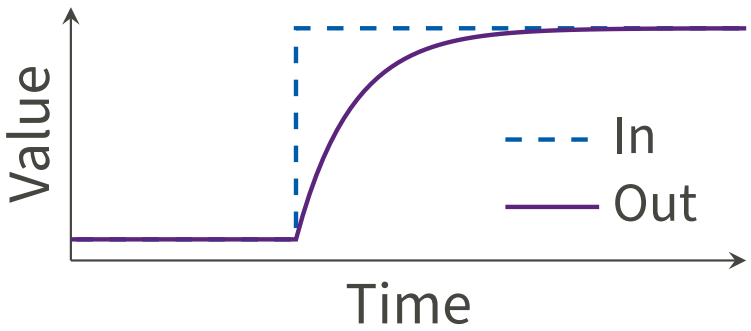




$$y = g \cdot \tanh(m \cdot x - d)$$

First Order Lag

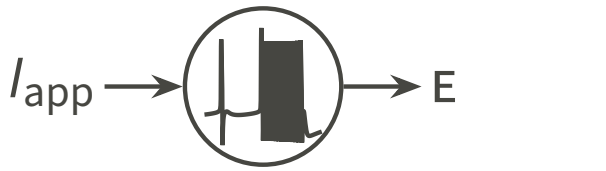


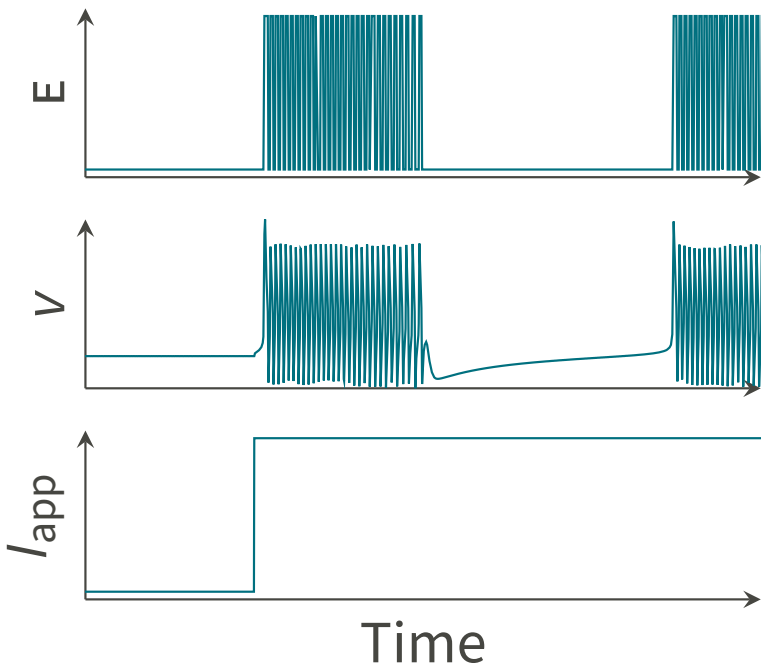


$$\tau \dot{y} = x - y$$

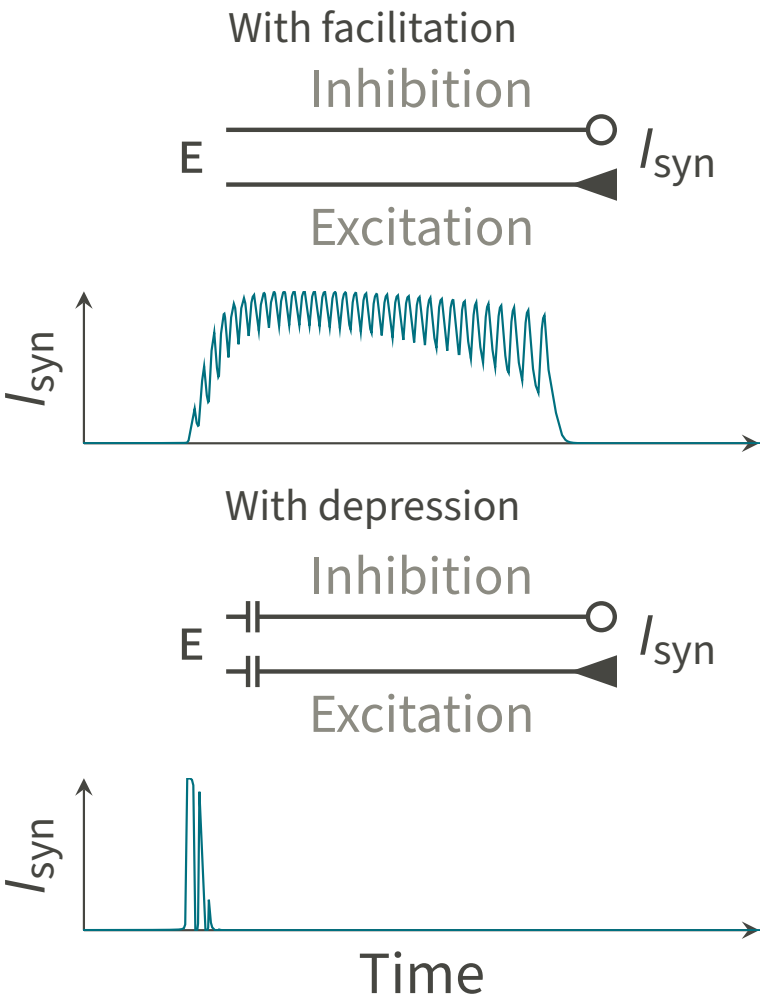
From the primitives : Neurons and Synapses

Mixed-Feedback Neuron [1]



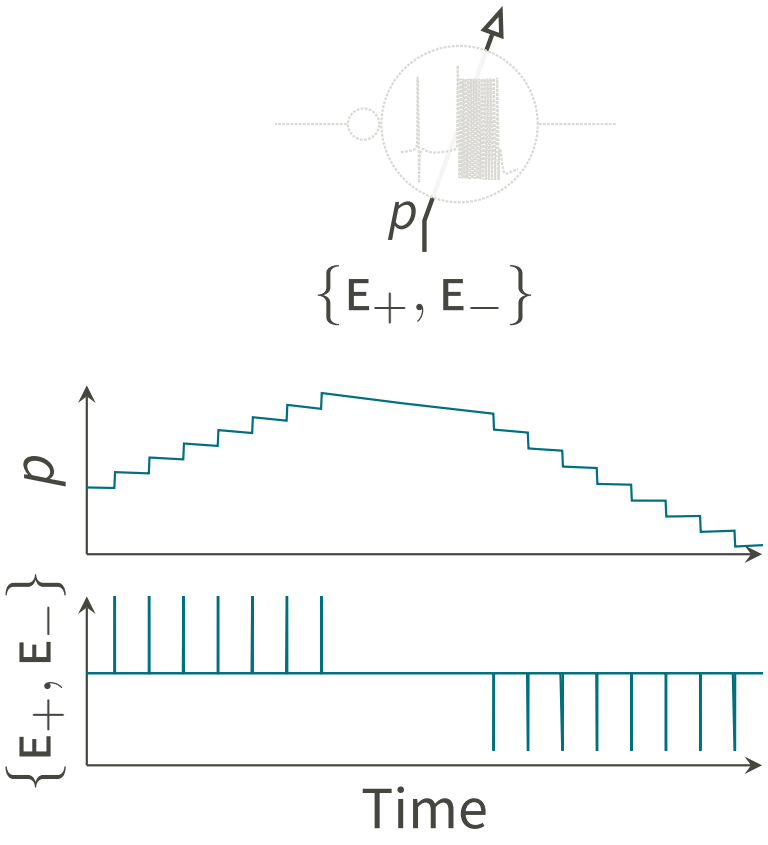


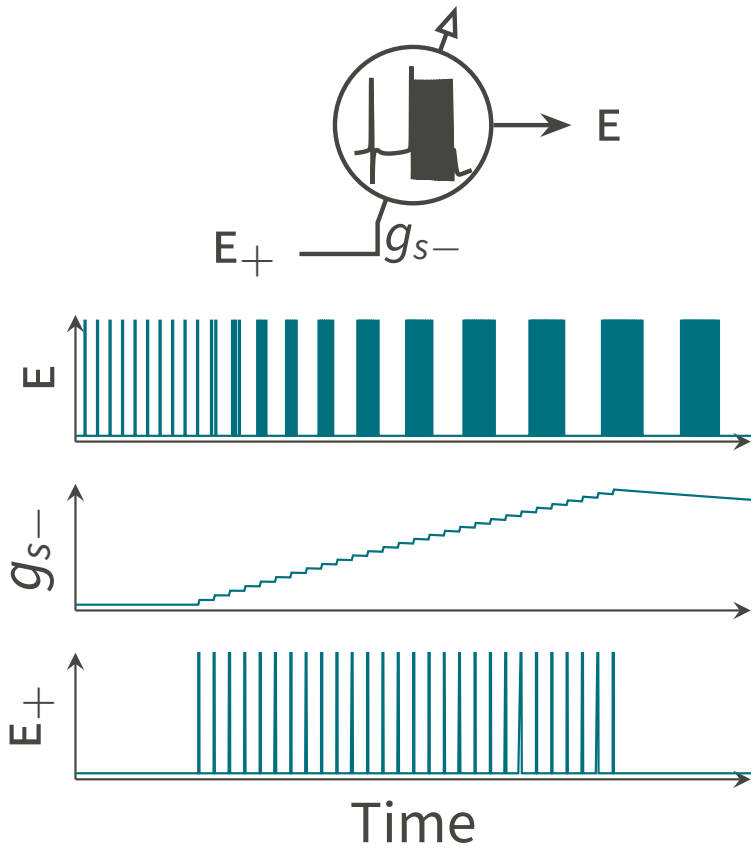
Synapses



[1] Ribar and Sepulchre (2019) “Neuromodulation of Neuromorphic Circuits”

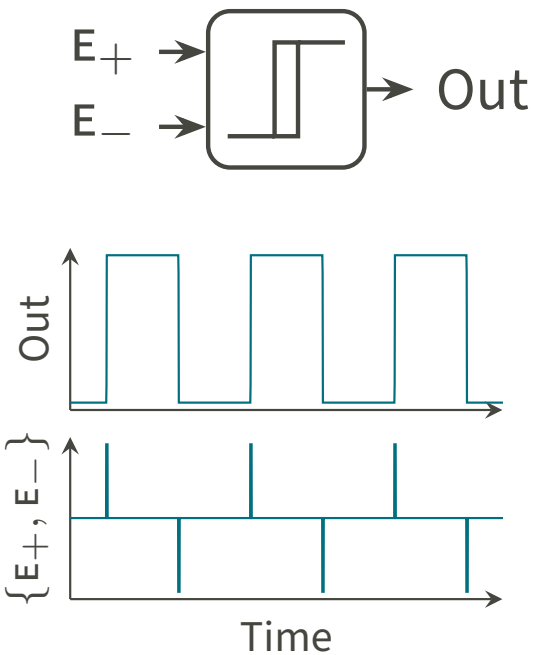
Controlling Neuron : Modulation



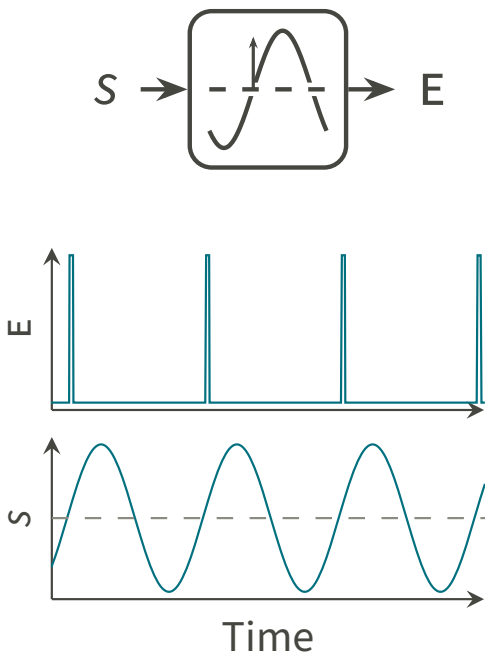


Other Useful Computation Blocks

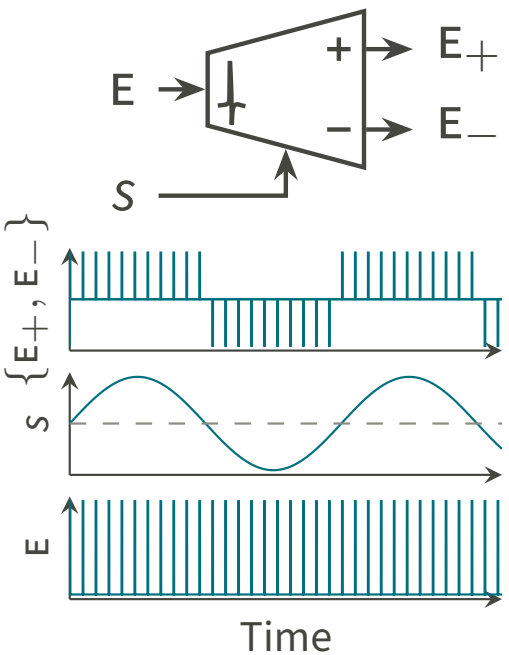
Bistable Relay



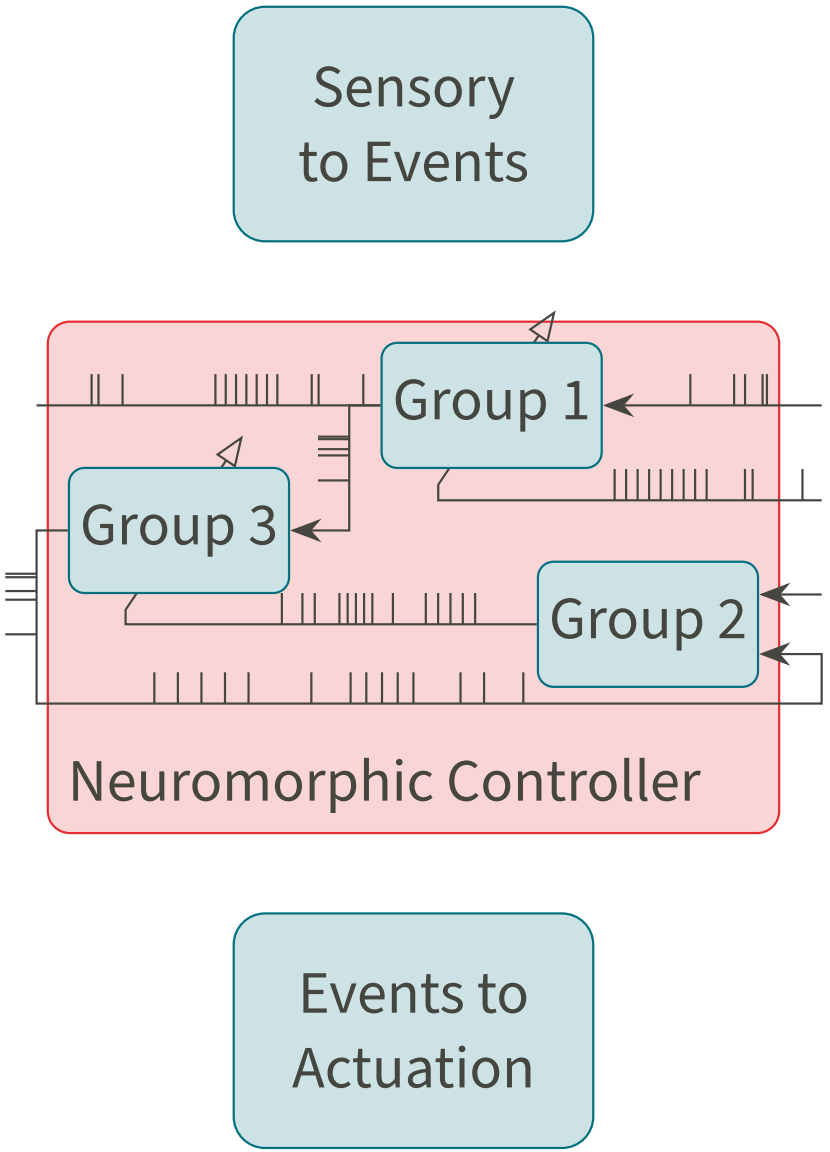
Directional Threshold Detector



Event Selector



Where does it fit in the Paradigm ?



Constraints

- Organize computation into group.
- Communicate between groups using events.
- **BUT** possibility of continuous signal inside groups.

Unmentioned Blocks

- Event Handling Blocks

1. Introduction

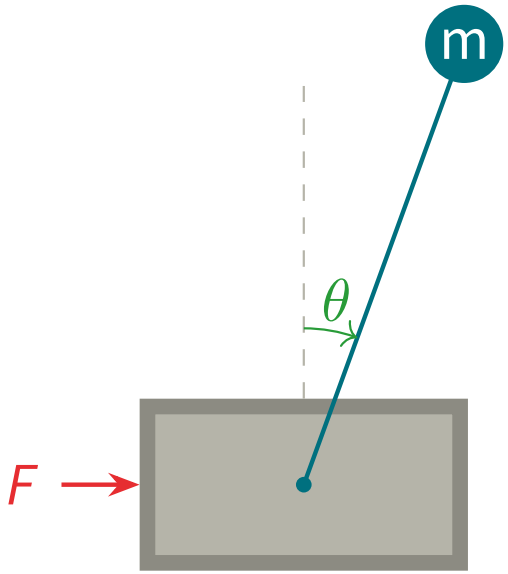
2. Toolbox

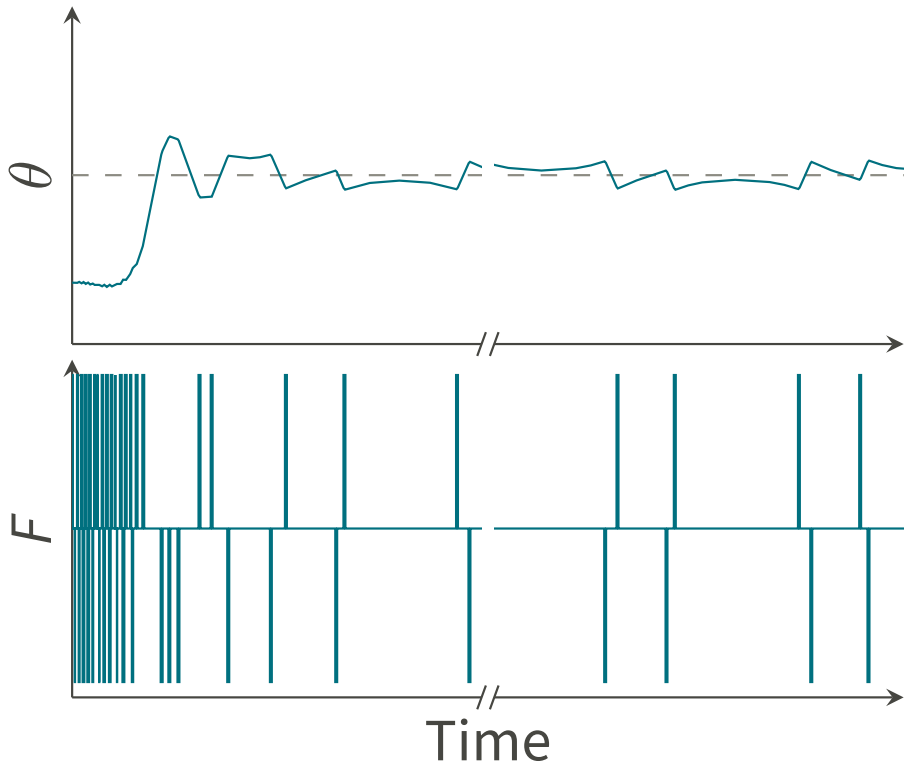
3. Examples

4. Conclusion

A Classical Approach : Spiky P(ID)

A Cartpole Example



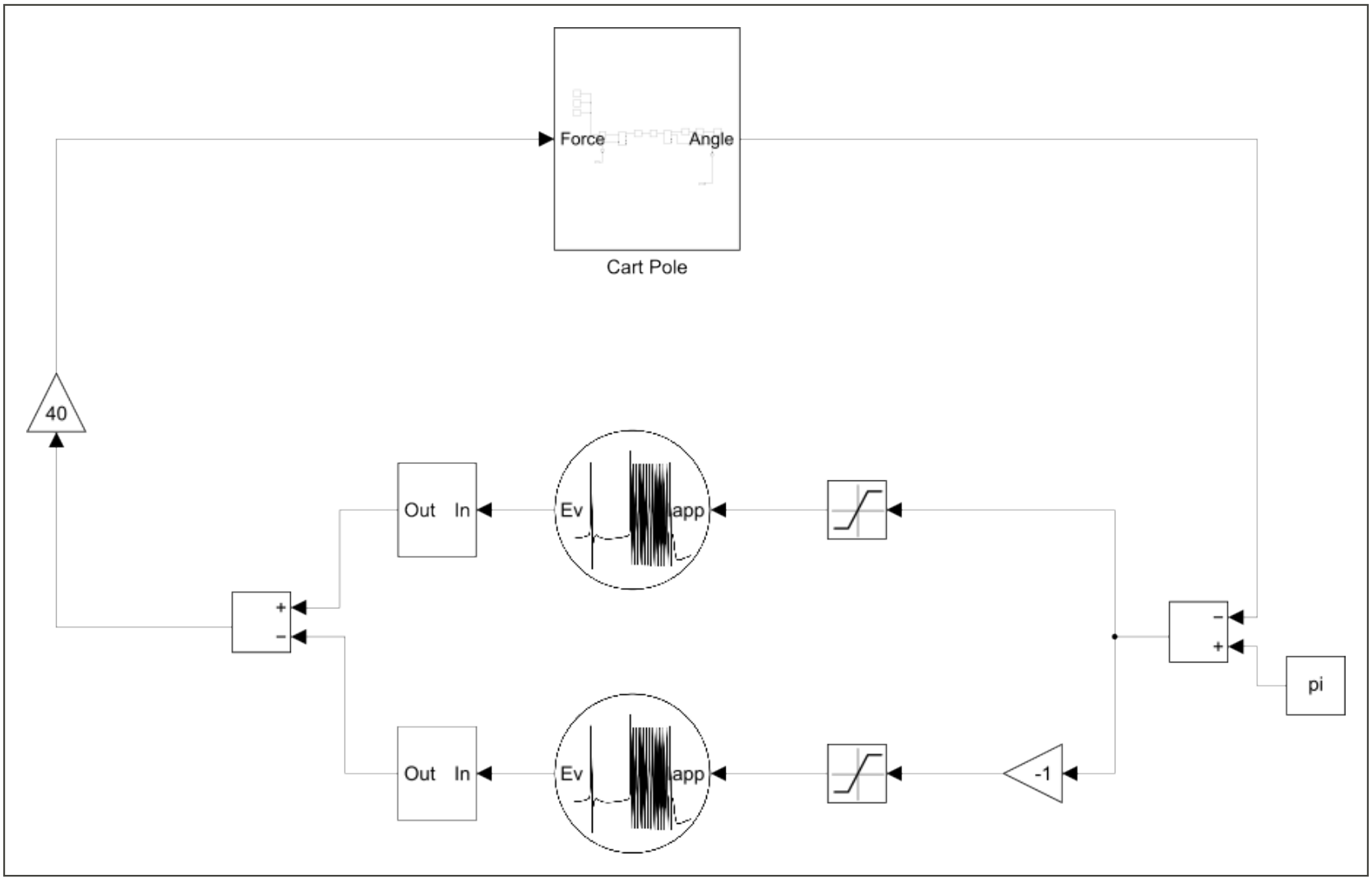


- **Problem** : control the force *F* to keep the pendulum vertical.

Webb, Davies, and Lester (2011) “Spiking neural PID controllers”

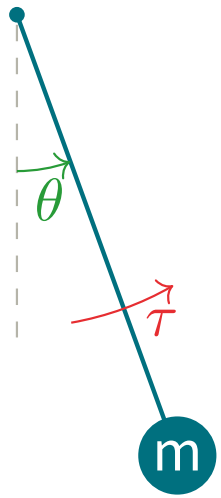
A Classical Approach : Spiky P(ID) (cont.)

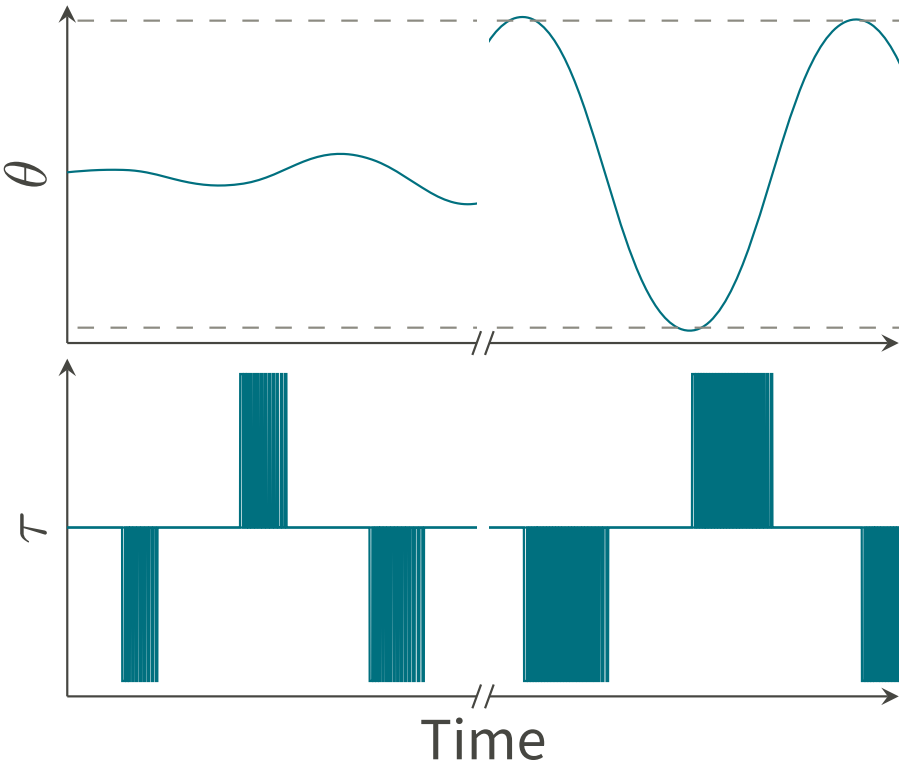
A Cartpole Example



Our Approach : Rythmic Control

A Pendulum Example

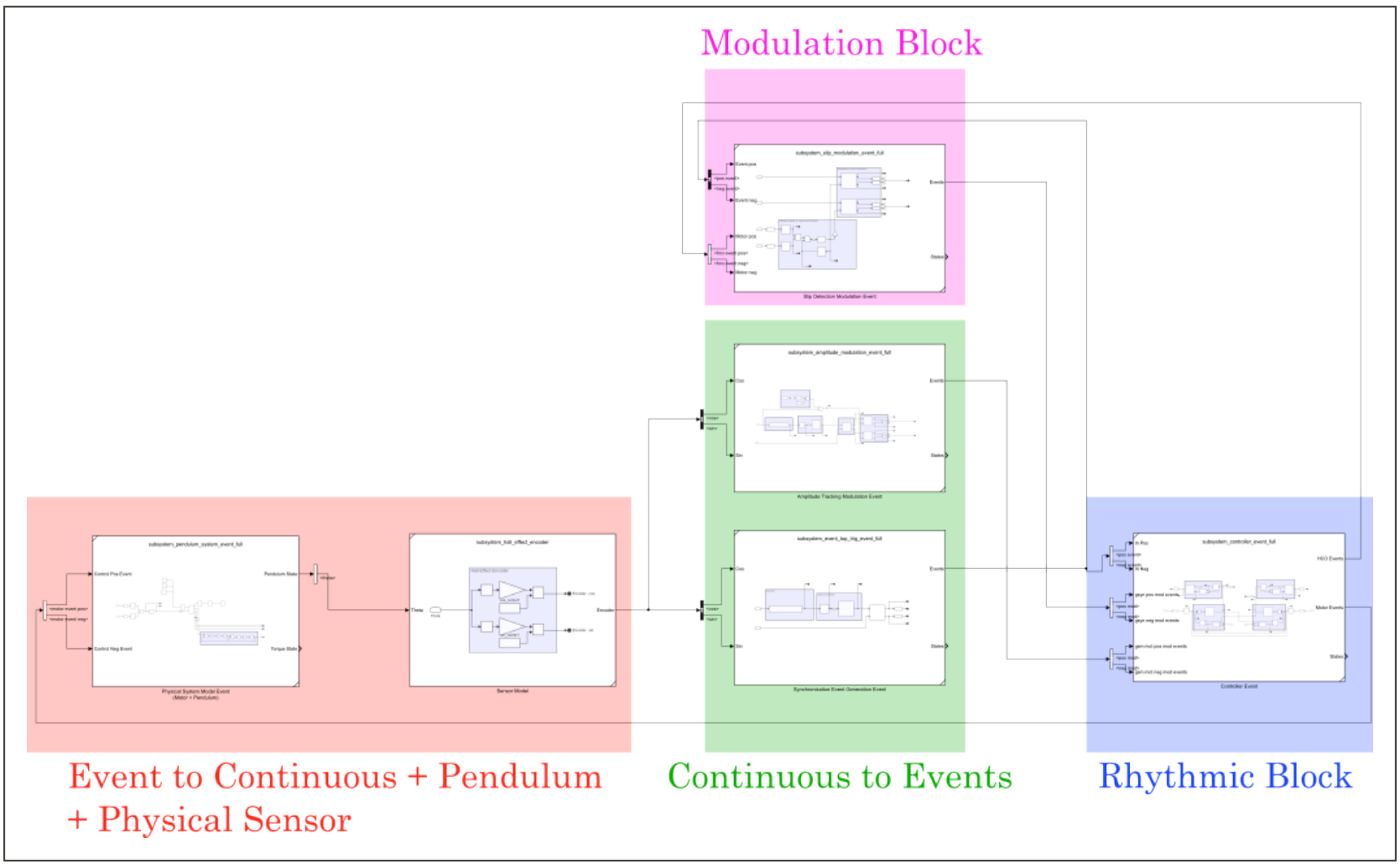




- **Problem** : control the torque τ to keep the pendulum oscilating at a certain amplitude.

Our Approach : Rythmic Control (cont.)

A Pendulum Example



1. Introduction

2. Toolbox

3. Examples

4. Conclusion

Take home message

- The toolbox exist and is still an alpha version.
- A zoo of neuromorphic computing blocks can arise from two primitves.
- It is possible to use these neuromorphic blocks in feedback loops to control systems.

Further Perspectives ?

- Community Development.
  - Name : ”**Neuromorphic Toolbox for Control**”.
  - https://github.com/ChristianFernandezLorden/neuromorphic-toolbox-for-control
  - https://nl.mathworks.com/matlabcentral/fileexchange/180432-neuromorphic-toolbox-for-control
  - We can communicate if you have a specific application in mind.
- Analysis Tools (e.g. mismatch generator).

LIÈGE université
Neuroengineering Laboratory

BOSA Federal Public Service Policy & Support

Bibliography

- Ribar, Luka and Rodolphe Sepulchre (2019). “Neuromodulation of Neuromorphic Circuits”. In: *IEEE Transactions on Circuits and Systems I: Regular Papers* 66.8, pp. 3028–3040. DOI: 10.1109/TCSI.2019.2907113.
- Schmetterling, Raphael et al. (2024). “Neuromorphic Control of a Pendulum”. In: *IEEE Control Systems Letters* 8, pp. 1235–1240. ISSN: 2475-1456. DOI: 10.1109/lcsys.2024.3409093. URL: http://dx.doi.org/10.1109/LCSYS.2024.3409093.
- Webb, Andrew, Sergio Davies, and David Lester (2011). “Spiking neural PID controllers”. In: *International Conference on Neural Information Processing*. Springer, pp. 259–267.