

Mitigating mismatch using neuromodulation loops

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Christian FERNANDEZ LORDEN

Alessio FRANCI

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`Christian.FernandezLorden@uliege.be`

1. Defining mismatch

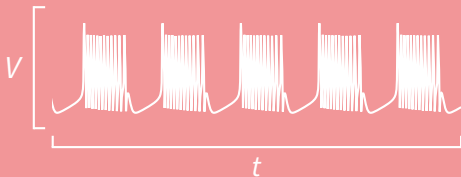
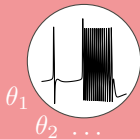
2. HCO Example

3. Mismatch in Control

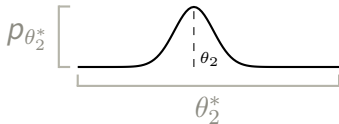
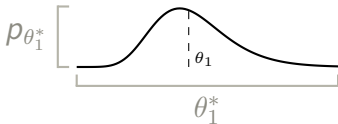
4. Conclusion

What is (parameter) mismatch ?

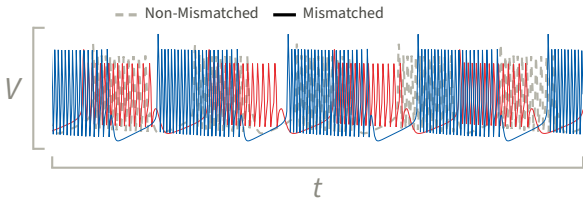
Model



Implementation

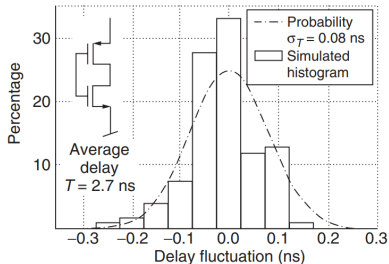


Yields



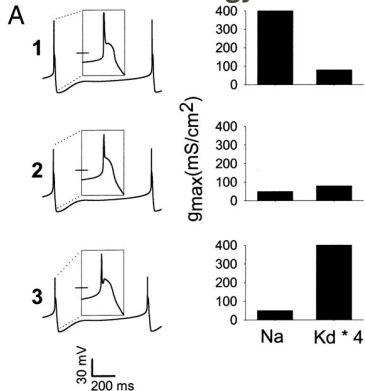
Why do we care about mismatch ?

Electronics



From Klimach et al. (2006) "MOSFET mismatch modeling"

Biology



From Marder (2011) "Variability, compensation, and modulation in neurons and circuits"

How is mismatch handled ?

Electronics

Mismatch is reduced by:

Digital

- Use only high and low value

Analog

- Layout techniques
- Increase transistor size
- Active (homeostatic) compensation

Biology

Mismatch is not reduced, but is controlled through:

- Homeostatic loops
- Neuromodulation



Could biological techniques be used to interconnect mismatched neuromorphic circuits to produce robust behavior ?

Modeling and simulation tools



Neural Blocks



Auxiliary Blocks



Events Transmission Blocks



Quick Insert



First Order Lag



Tunable Sigmoid

From Fernandez Lorden (2026)

Implements mixed-feedback neuron model (Ribar and Sepulchre 2019) and derived blocks.

1.

Defining mismatch

2. HCO Example

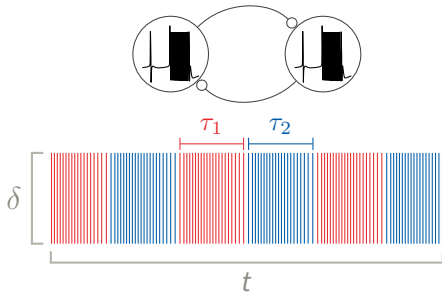
3.

Mismatch in Control

4.

Conclusion

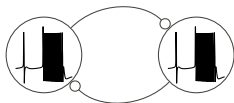
An HCO sharing problem



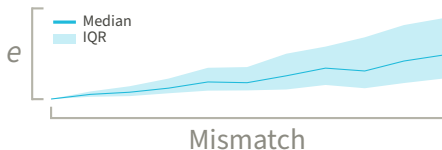
- Goal: Share the activity period 50/50 per neuron
- Trivial with perfectly chosen parameters
- Already 44 mismatched parameters

$$e = \frac{|\left(\sum_{\tau_1 \in \mathcal{P}_1} \tau_1\right) - \left(\sum_{\tau_2 \in \mathcal{P}_2} \tau_2\right)|}{\left(\sum_{\tau_1 \in \mathcal{P}_1} \tau_1\right) + \left(\sum_{\tau_2 \in \mathcal{P}_2} \tau_2\right)}$$

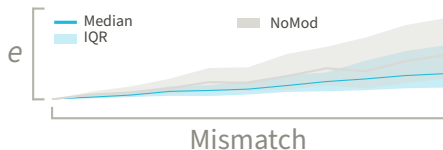
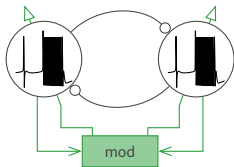
Mismatch gradually destroys the goal



- Mismatch in neurons and synapses gradually degrades performance.
- This system is still reliable at low mismatch



Modulation reduces mismatch effects



- Mismatched neuromodulatory-like regulation loop
- Error still increases with time
- Error lower than without modulation

1.

Defining mismatch

2.

HCO Example

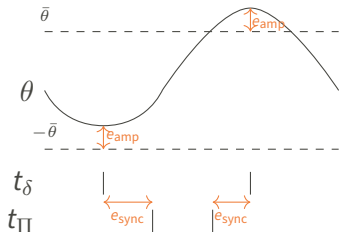
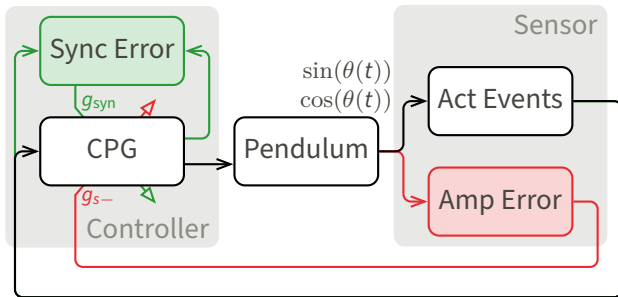
3.

**Mismatch
in Control**

4.

Conclusion

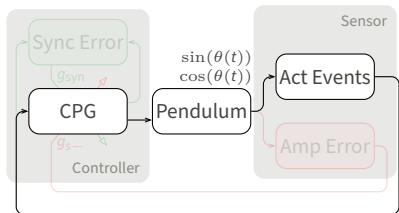
Controlling a pendulum



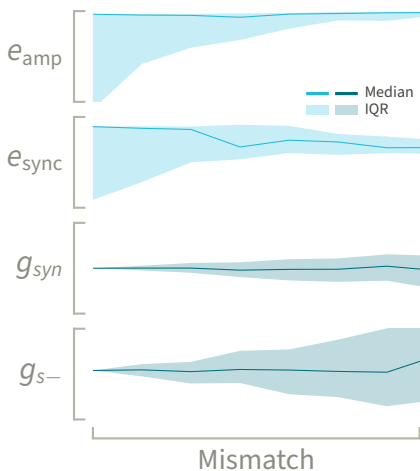
$$e_{amp} = \frac{1}{|\mathcal{T}_\delta|} \sum_{t_\delta \in \mathcal{T}_\delta} |\bar{\theta} - |\theta(t_\delta)||$$

$$e_{sync} = \frac{1}{|\mathcal{T}_{\delta-\Pi}|} \sum_{(t_\delta, t_\Pi) \in \mathcal{T}_{\delta-\Pi}} |t_\delta - t_\Pi|$$

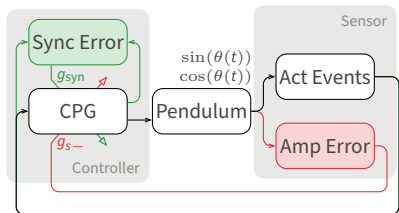
Mismatch is catastrophic



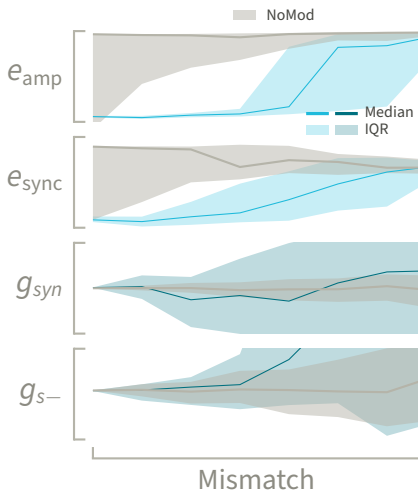
- Only the direct control loop is active
- Even without mismatch, some simulations fail (due to noise)
- Tiny mismatch breaks the controller



Modulation restores control



- Modulation control loops are active
- Controller can handle some mismatch before failing
- Modulation varies g_{syn} and g_{s-} to compensate mismatch



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Take home message

- Mismatch is a phenomenon that is inherent to electronics and biology.
- Mismatch should be considered when designing of neuromorphic circuits.
- Neuromodulation loops can be used to mitigate mismatch and preserve the functionality of neuromorphic systems and arise naturally in control tasks.
- Counteracting mismatch is countering the detrimental effect on results, not chasing the exact same solution.

Limitations and Further Perspectives

Limitations

- The examples shown are simple and may not capture the full complexity of mismatch in real, larger-scale systems.

Further Perspectives

- Investigate the effects of mismatch in more complex neuromorphic systems.
- Find more systematic modulation strategies to mitigate mismatch (using more control oriented analysis like Petri et al. (2024)).

Bibliography i

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Bibliography ii

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