Biological-plausible learning with a two compartment neuron model in recurrent neural networks

Timo Oess[1,2], Daniel Schmid[2] & Heiko Neumann[2]
[1] *Applied Cognitive Psychology, University of Ulm, Germany*
[2] *Institute for Neural Information Processing, University of Ulm, Germany*

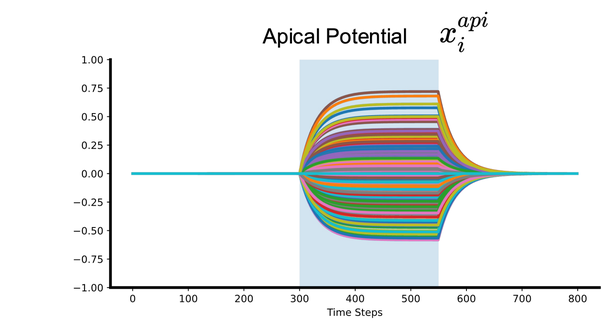
Introduction

- Human motor system acts in accordance with an optimal feedback control (OFC)[1]
- Recurrent neural networks (RNNs) can provide models of human motor control system[2]
- Often backpropagation through time (BPTT) is used to train such networks
- Integration site of feedback signal is unclear

We propose an RNN with 2-point neurons which integrates sensory feedback via apical dendrites[3] and controls a dynamical system via biologically plausible Neo-Hebbian reward-based node-perturbation learning[4]

Methods

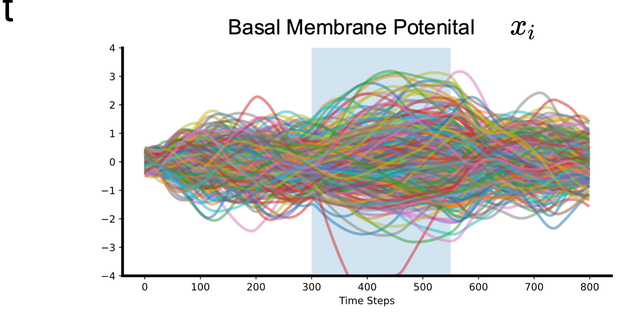
- 2-point leaky integrator (LI) neuron model with apical and basal and compartments[5]
- Sparse reward-modulated Hebbian weight update via node perturbations[1]
- RNN controls plant (dynamical system) via acceleration control commands
  - End of trial reward based on difference between goal and plant end position
  - Perturbations applied to plant states

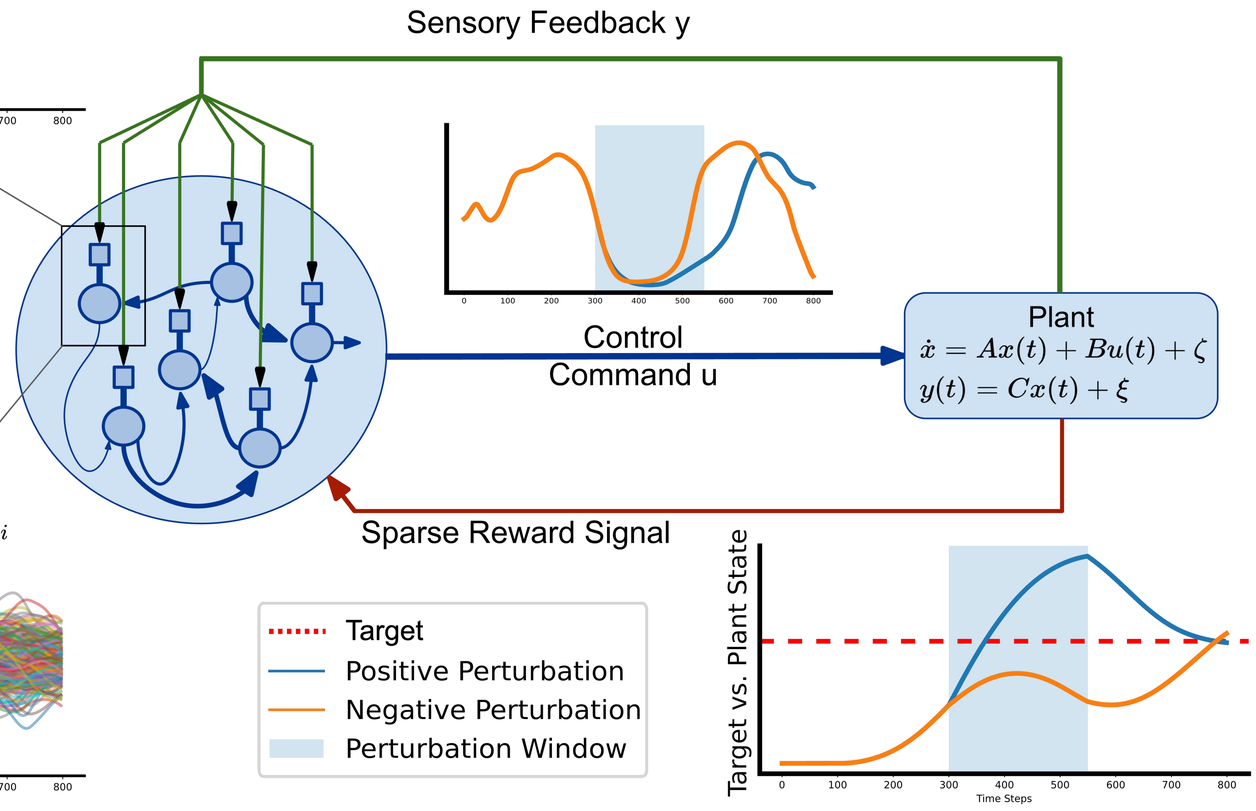


$$\tau \dot{x}_i^{api} = -x_i^{api} + W^{in} \cdot y$$

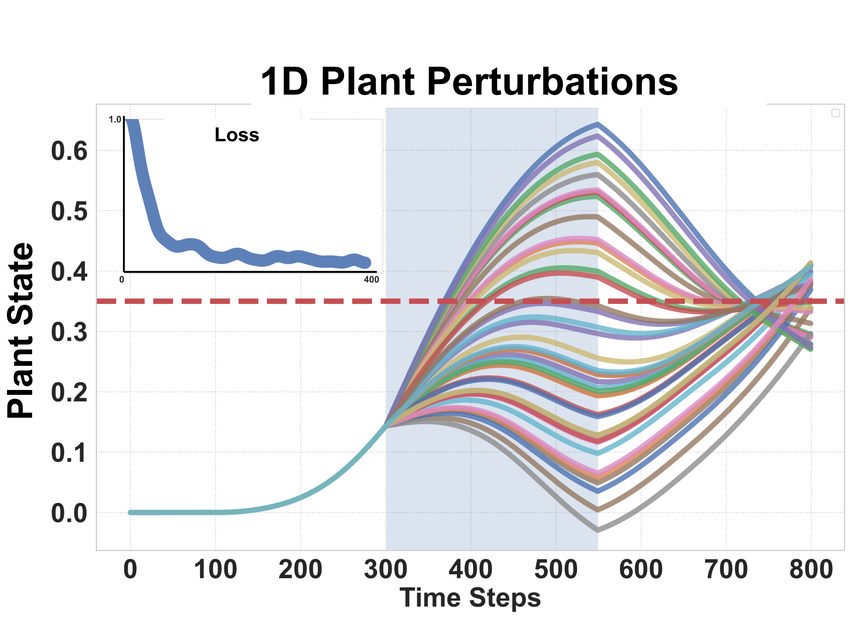
$$\tau \dot{x}_i = -x_i + s_i^{Rec} + x_i^{api}(\gamma + \xi s_i^{Rec})$$

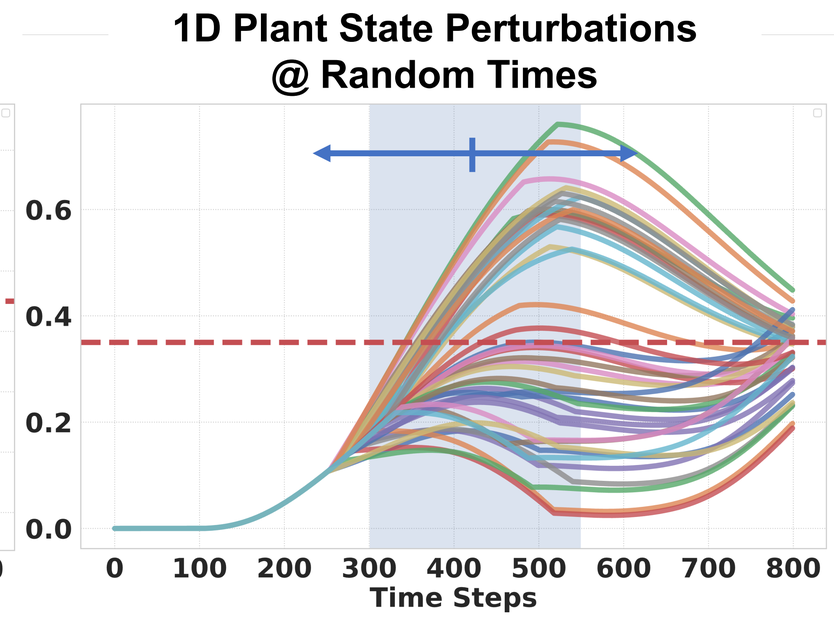
$$s_i^{Rec} = W^{Rec} * tanh(X)$$

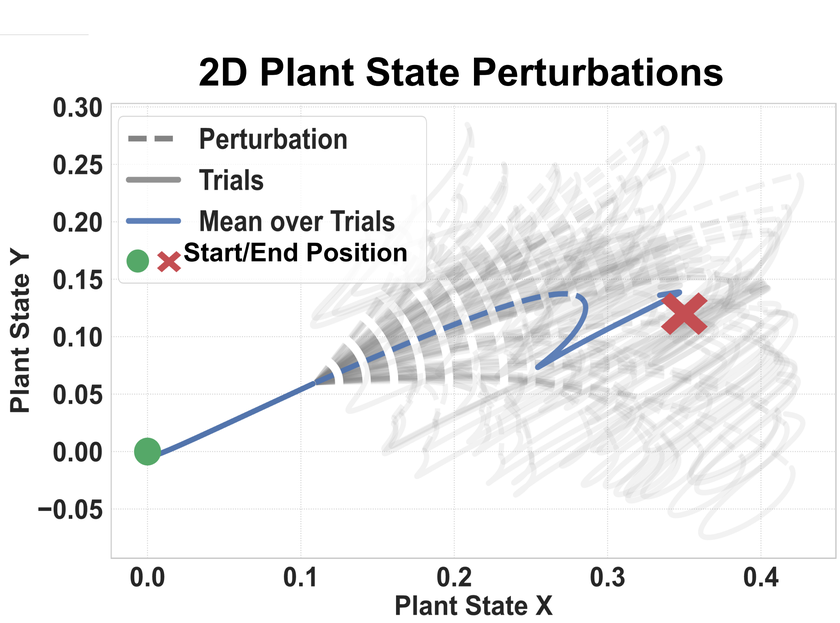


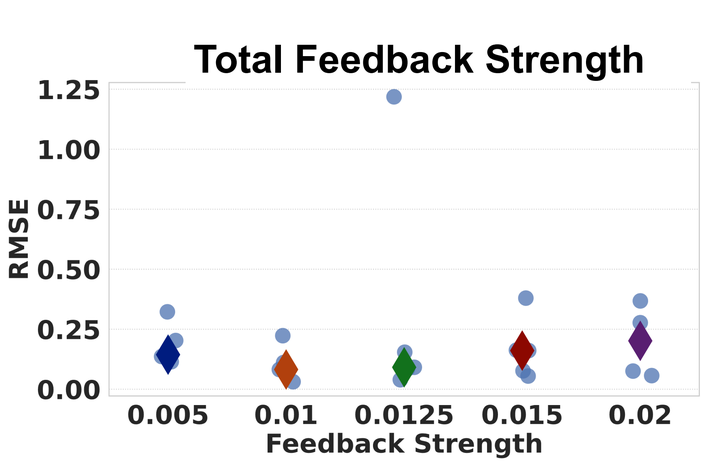


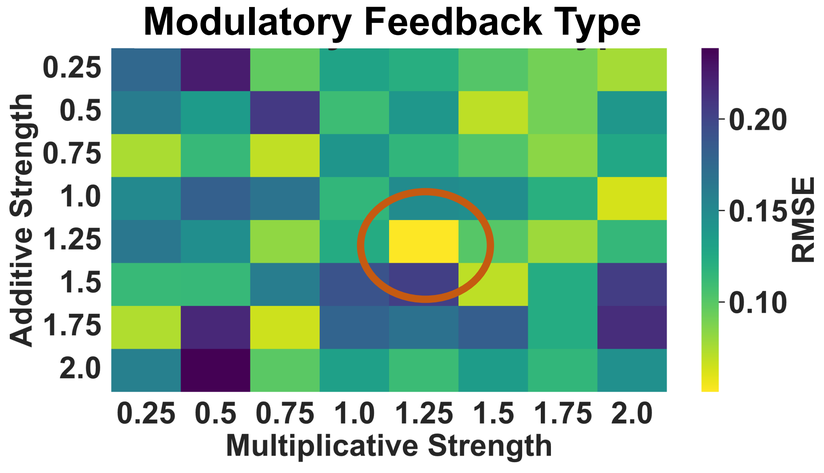
Results











Conclusion

- Successful integration of sensory feedback via apical dendrites
- Combination of additive and multiplicative integration most reliable
- Model scales easily to ore complicated 2D plant. Control signals are acceleration commands in x- and y-direction

Future Work

- Testing 2-point model against single compartment model with direct (excitatory) inputs
- 6 DOF arm model as plant with non-linear dynamics and investigation of optimality in terms of optimal feedback controller
  - Center-out reaching task with different targets
  - Minimum intervention principle

Contact

timo.oess@uni-ulm.de
https://oesst.github.io

References

[1] Todorov et al., *Nature neuroscience 2002*
[2] Sussillo et al. Current Opionion, 2014
[3] Larkum et al., *Nature*, 1999
[4] Miconi T., *eLife*, 2017
[5] Adeel et al.

Acknowledgements:

Thanks to Prof. Carsten Mehring for valuable discussions and input.