University of Exeter

Inference and Control of Neurons

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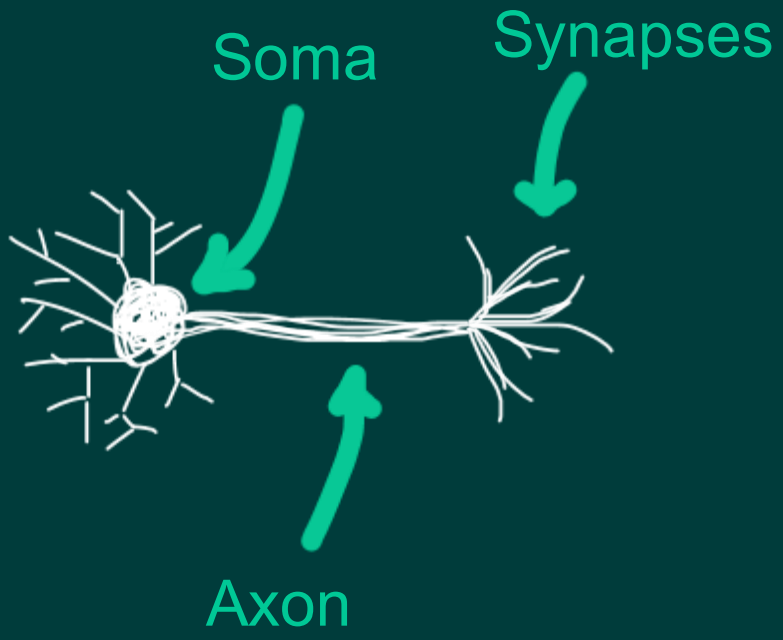
1. Experiment with neurons

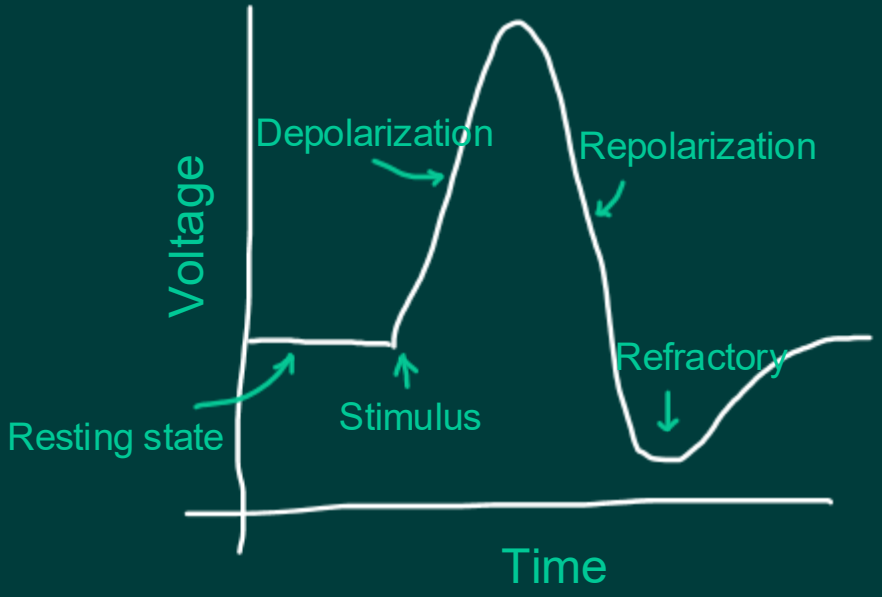
joint work with Akshita Jindal, Pragati Thakur Kyle Wedgwood.

2. Time-series analysis

joint work with Nicolás Rubido, University of Aberdeen.

What is a neuron?





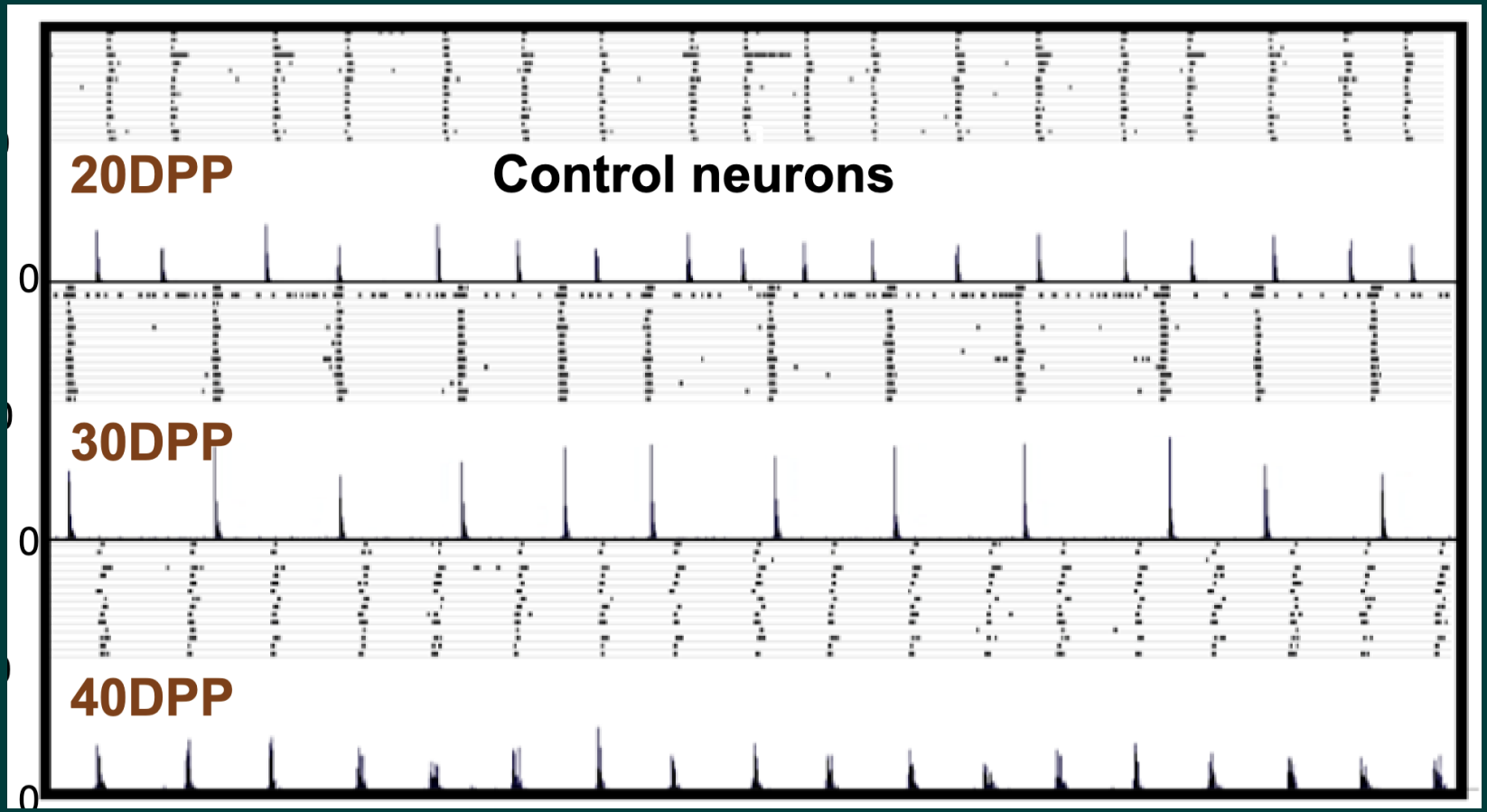
What is a neuron?

$$\frac{dV_i}{dt} = f(V_i) + \sum_j a_{ij}\, g(V_i, V_j) + I_i$$

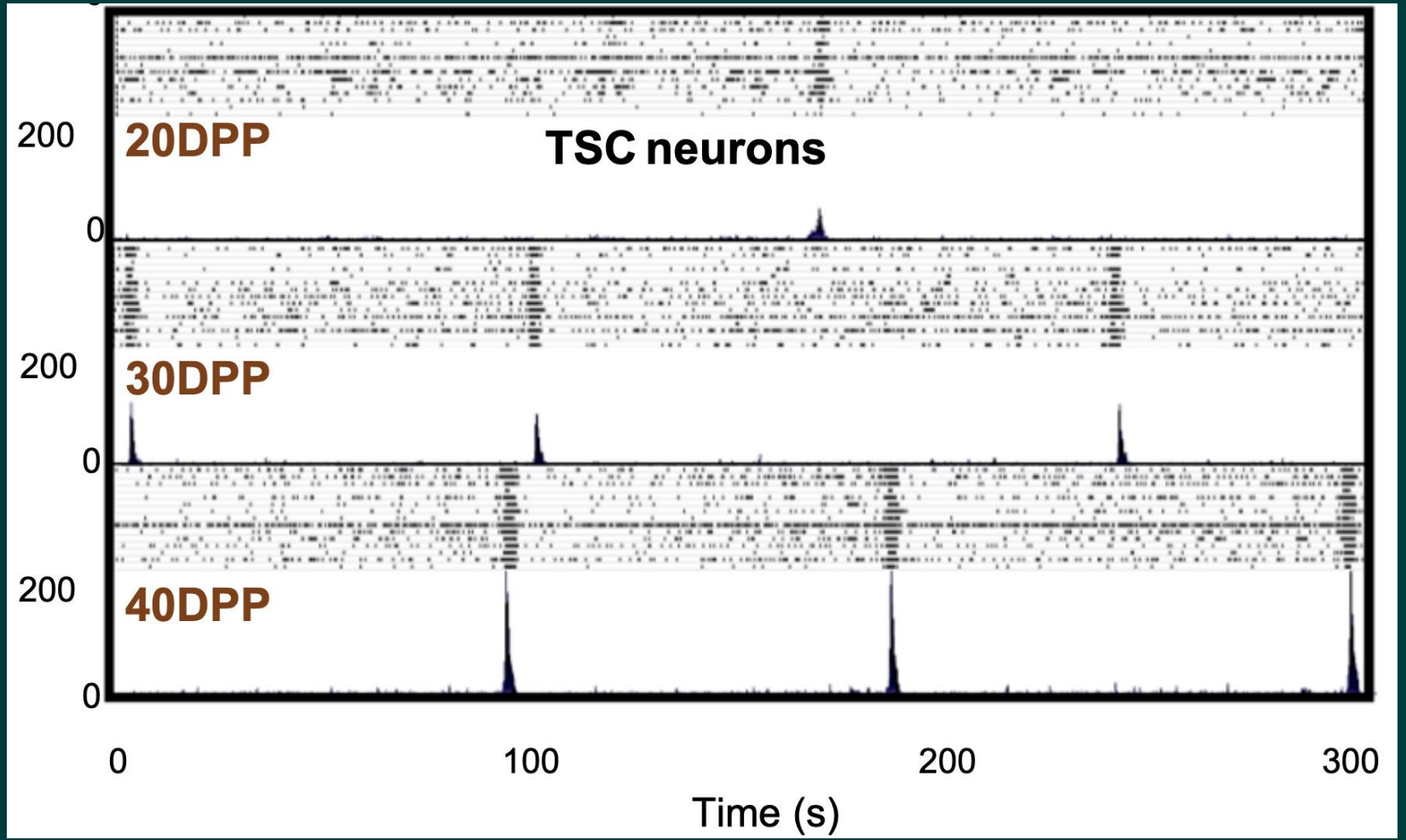
Internal dynamics

Coupling term
e.g. gap junction

Current including
synaptic coupling

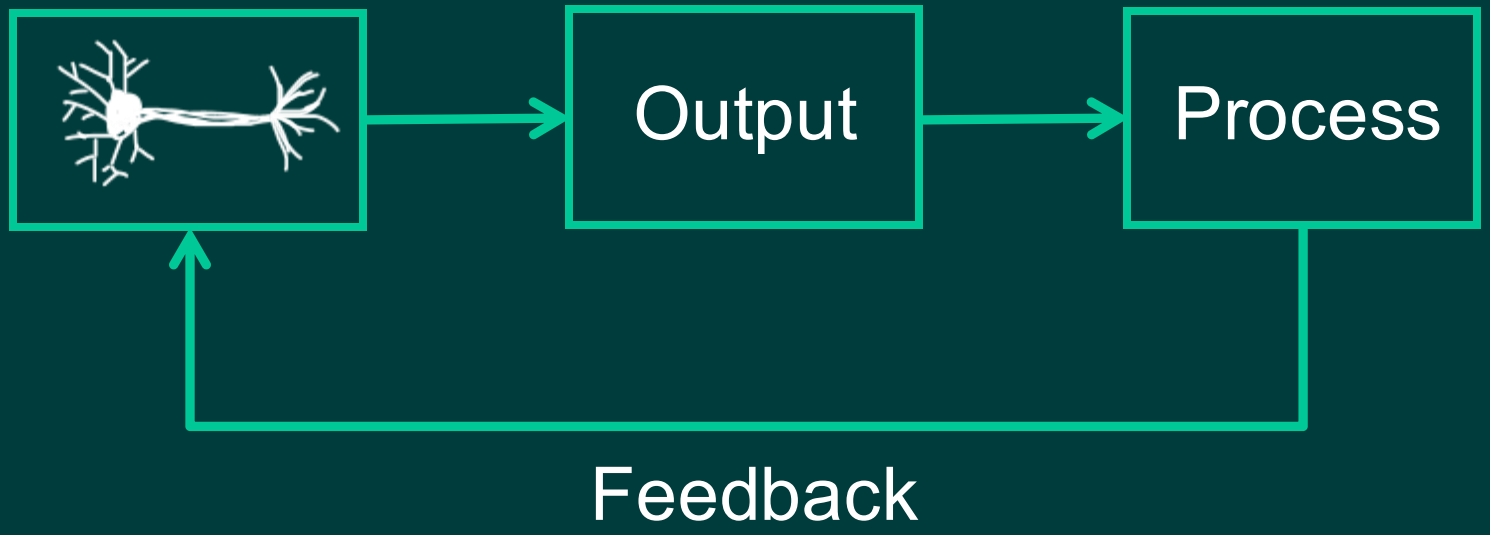


Alsaqati, M., Heine, V. M., & Harwood, A. J. *Molecular Autism*, ***11***, 1-13 (2020)



Alsaqati, M., Heine, V. M., & Harwood, A. J. *Molecular Autism*, ***11***, 1-13 (2020)

Control networks of neurons



Control networks of neurons

Closed-loop experiment with real-time manipulation of neurons to understand their behavior.

Some challenges:

- Control that is not invasive
- Neuron parameters unknown
- Neuron heterogeneity
- …

Non-invasive control of neurons

Optogenetics: Channelrhodopsin-2 (ChR2)

Non-invasive control of neurons

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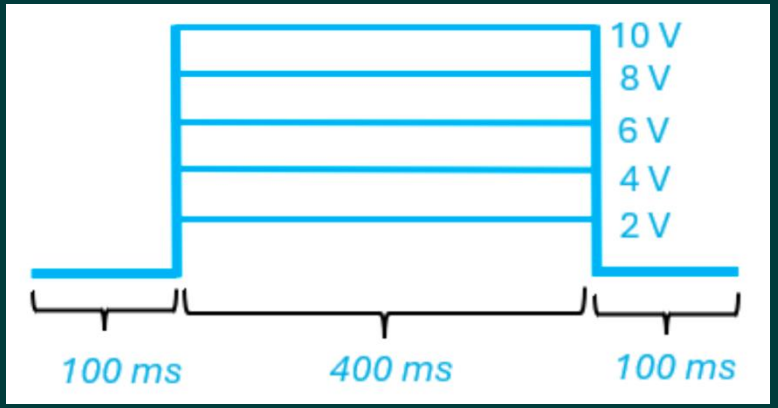

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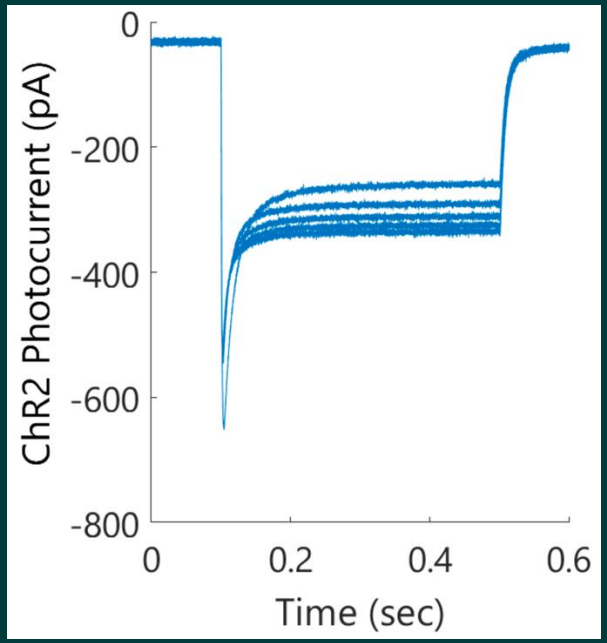

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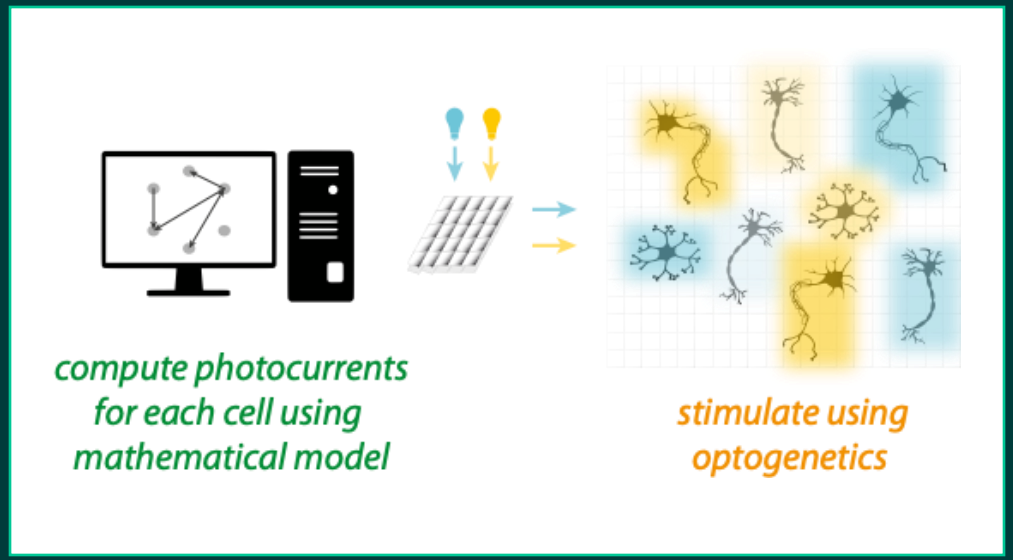

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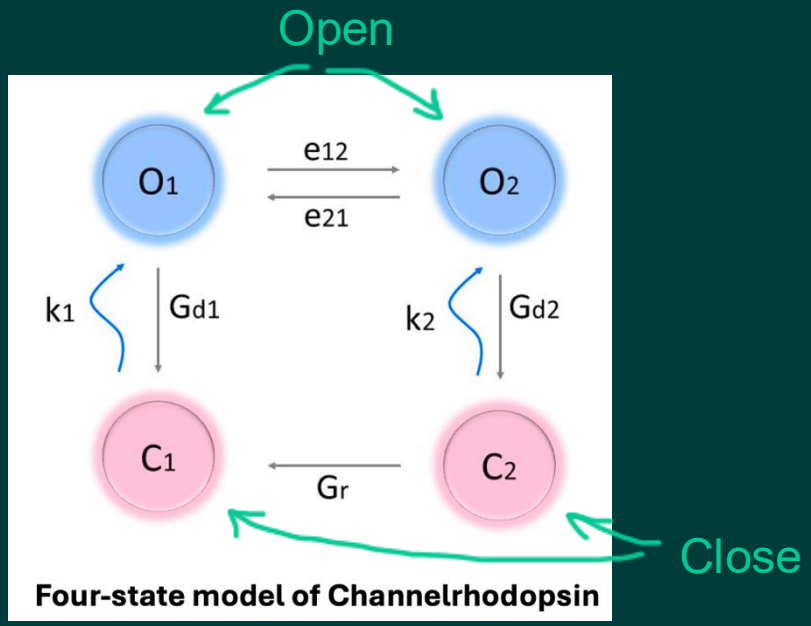
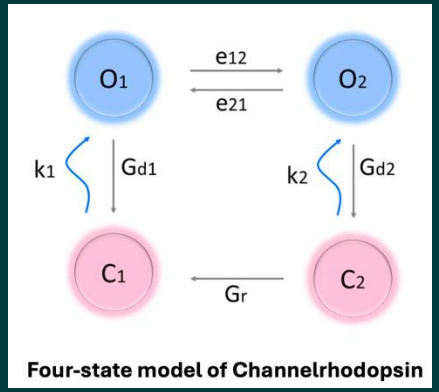


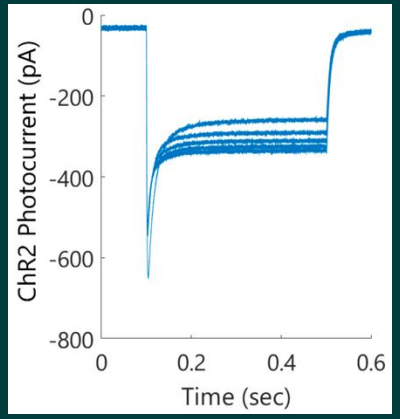
Non-invasive control of neurons

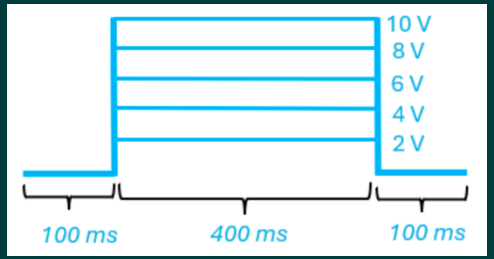
Bayesian Inference



Four-state model of Channelrhodopsin

+





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Model parameters

And uncertainty quantification!

Non-invasive control of neurons

Light design with optimal control

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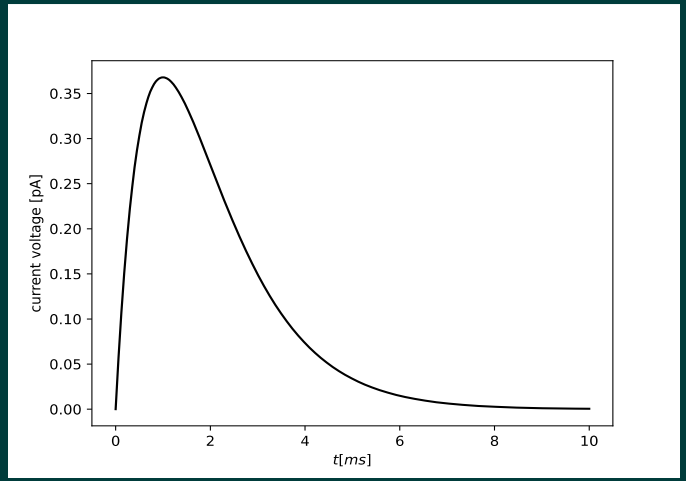

Non-invasive control of neurons

Light design with optimal control

$$F = \int_0^T C + constaints\ dt$$

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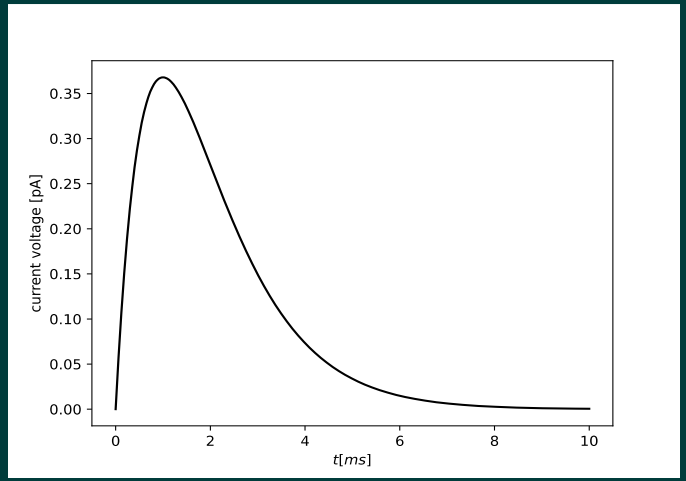

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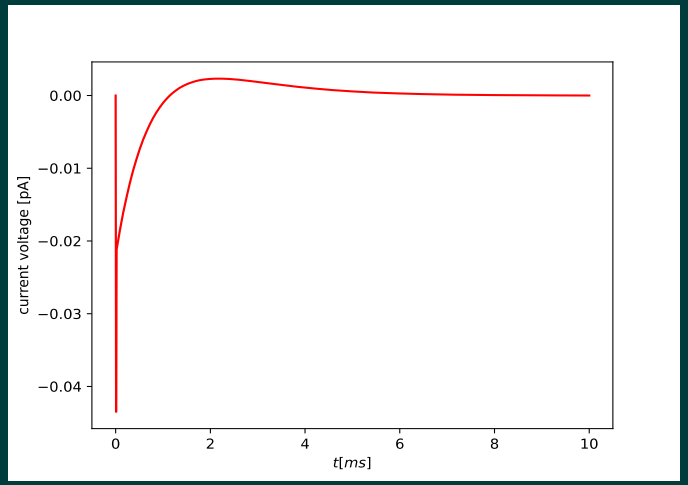

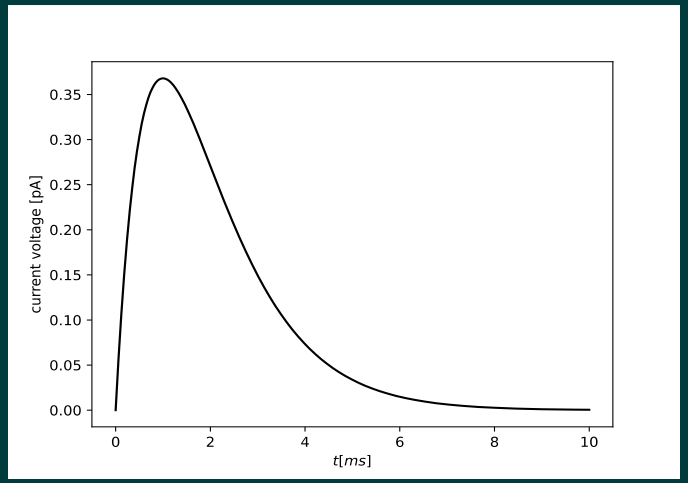

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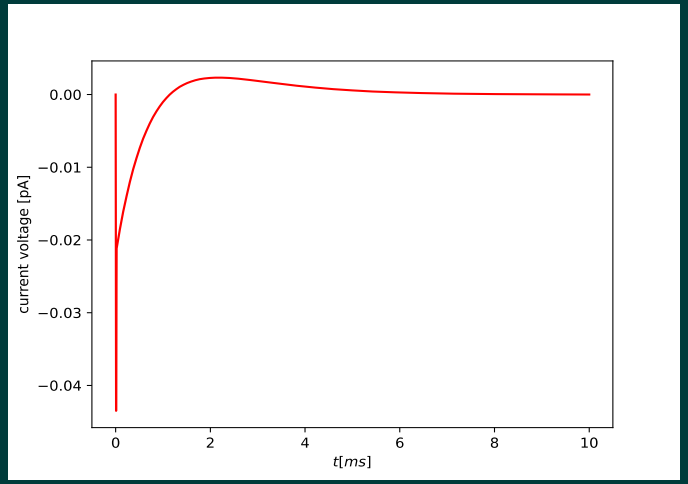

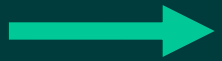

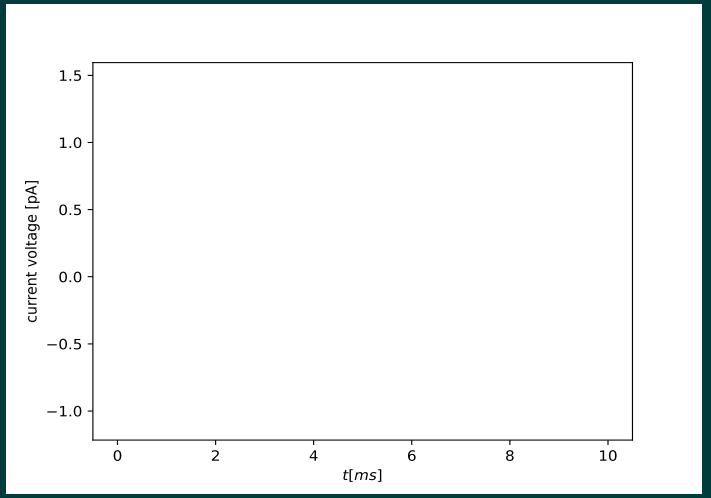

Non-invasive control of neurons

Validation experiment… working on it.

Non-invasive control of neurons

Validation experiment… working on it.

Next steps:

- Use Multielectrode arrays (MEA)
- Devise control strategies to perform specific tasks
- …

A way to include amplitude information from signals to ordinal pattern analysis *(submitted soon)*

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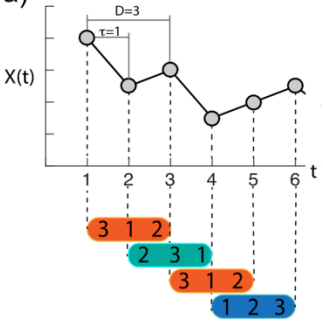
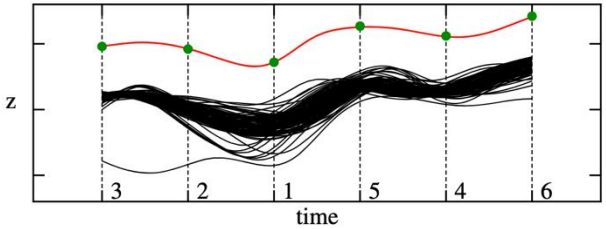
Ordinal patterns

a)



Zanin, M., Olivares, F. (2021). *Communications Physics*, *4*(1), 190.

Amplitudes



Politi, A. (2017. *Physical review letters*, *118*(14), 144101.

$$\langle \ln \sigma_i(j) \rangle$$

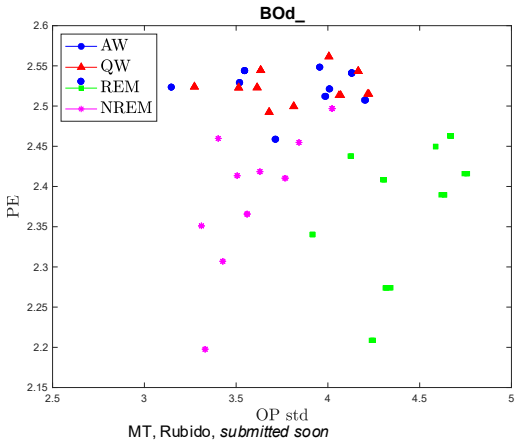
Permutation entropy

$$x = (4, 7, 9, 10, 6, 11, 3)$$

$$H(2) = -(4/6)\log(4/6) - (2/6)\log(2/6) \approx 0.918$$

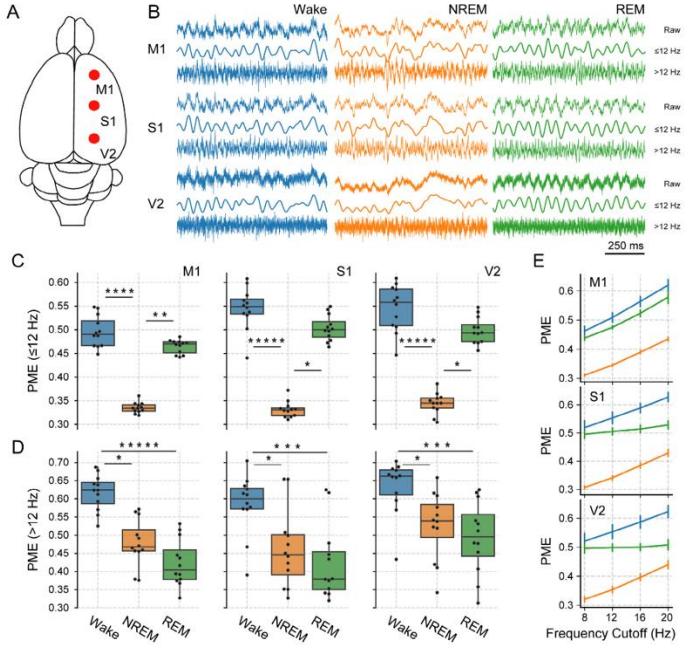
$$H(n) = -\sum p(\pi)\log p(\pi)$$

Bandt, C., & Pompe, B. (2002). *Physical review letters*, *88*(17), 174102.



MT, Rubido, *submitted soon*

Sleep/wake states



González, J., Mateos, D., Cavelli, M., Mondino, A., Pascovich, C., Torterolo, P., & Rubido, N. (2022). *Neuroscience*, *494*, 1-11.