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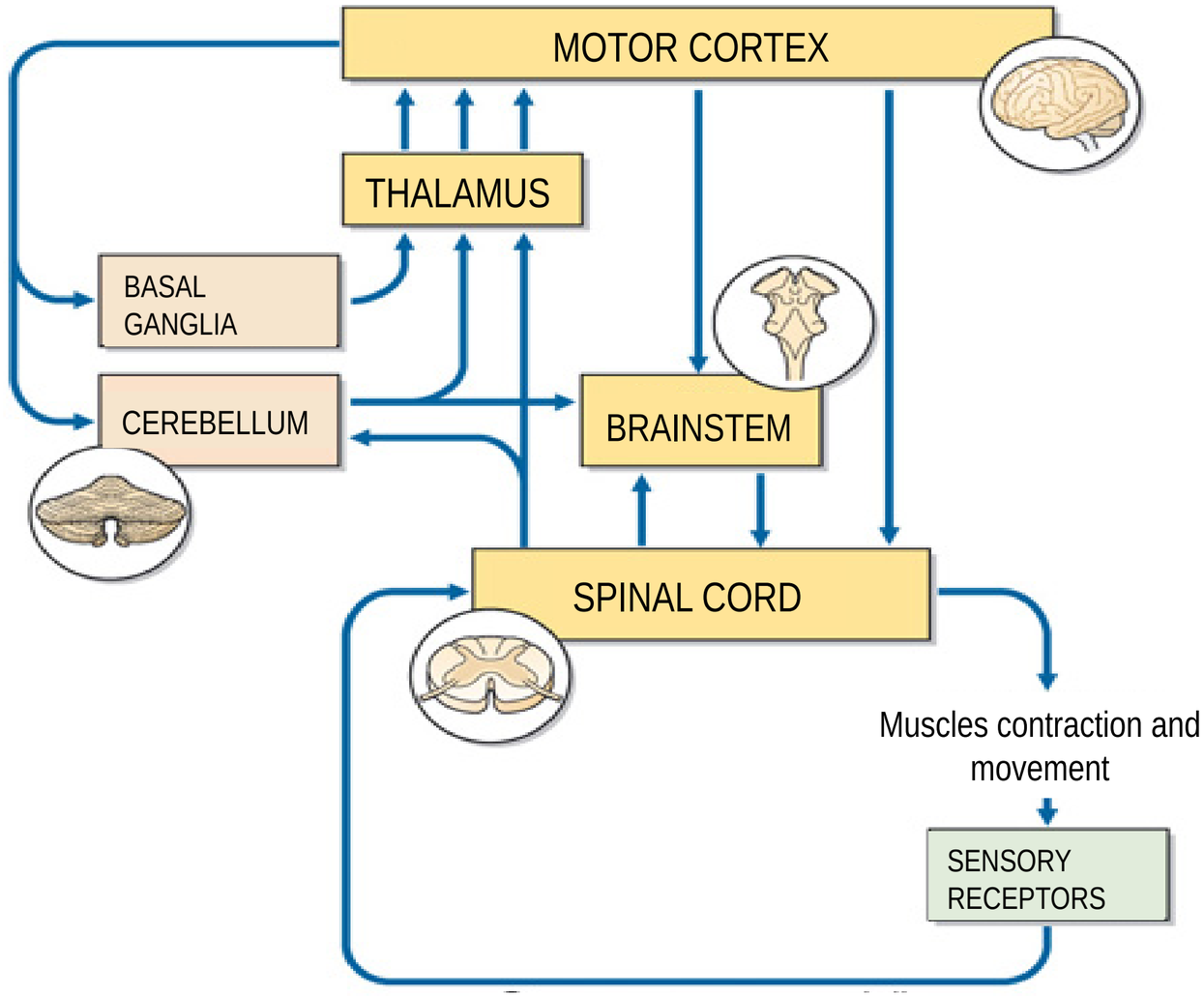
Integrating virtual brains with virtual bodies
Simulated robots for closed-loop in-silico experiments

Alberto Antonietti, University of Pavia – Politecnico di Milano

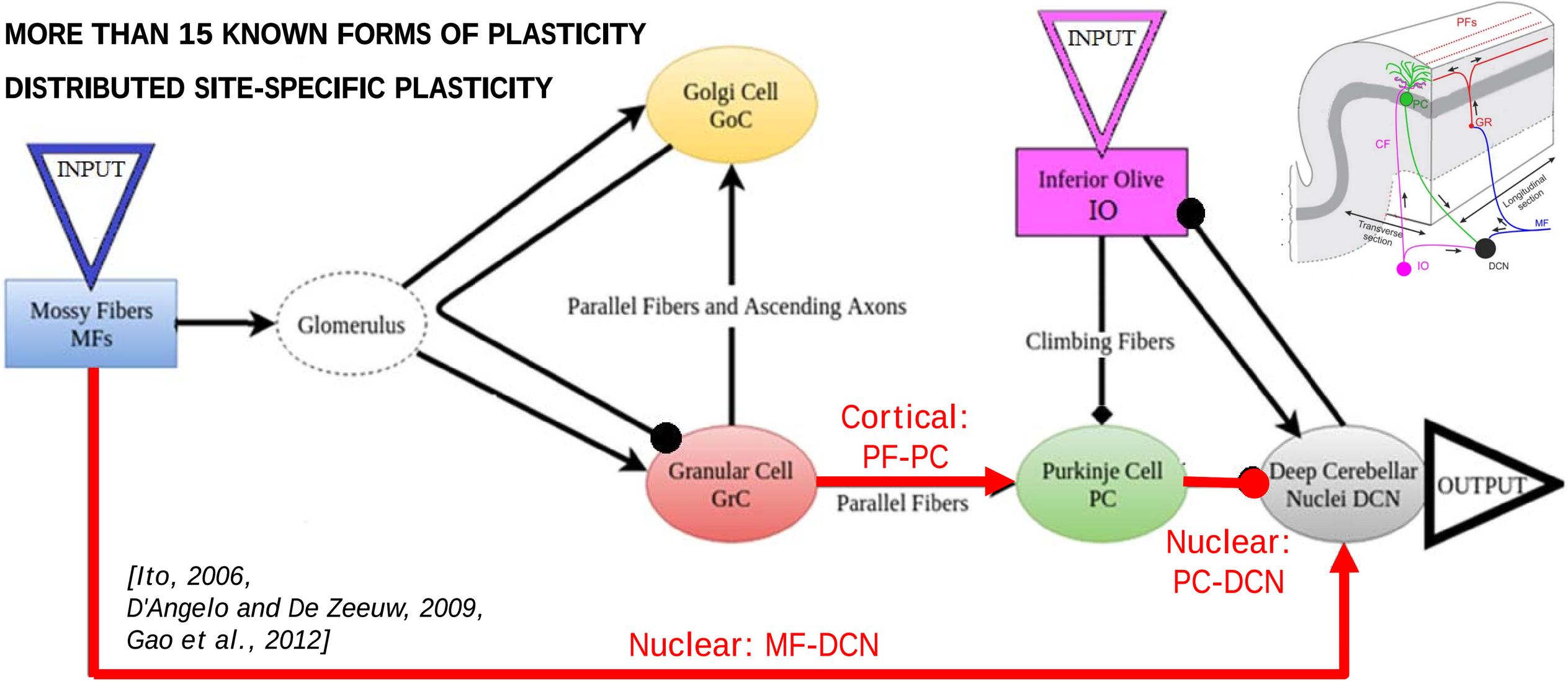
Brain areas involved in motor control



Physiological Background: the Plasticity

MORE THAN 15 KNOWN FORMS OF PLASTICITY

DISTRIBUTED SITE-SPECIFIC PLASTICITY



[Ito, 2006,
D'Angelo and De Zeeuw, 2009,
Gao et al., 2012]

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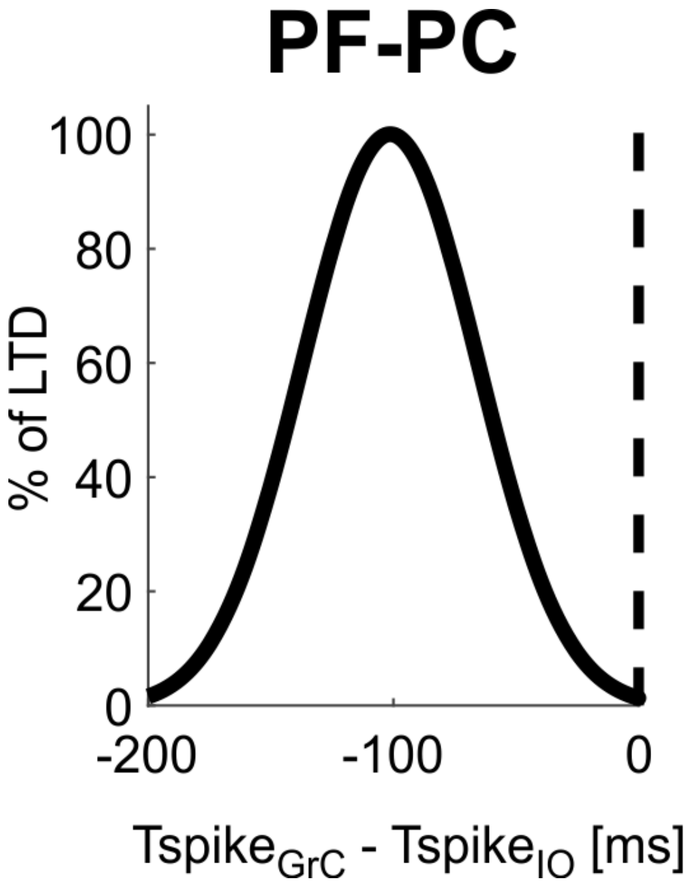
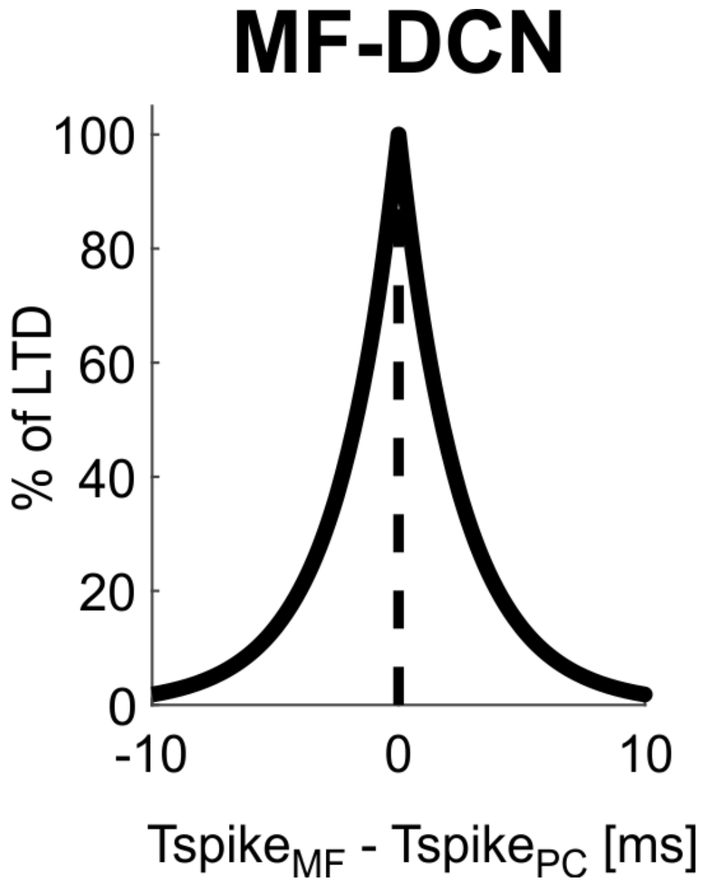
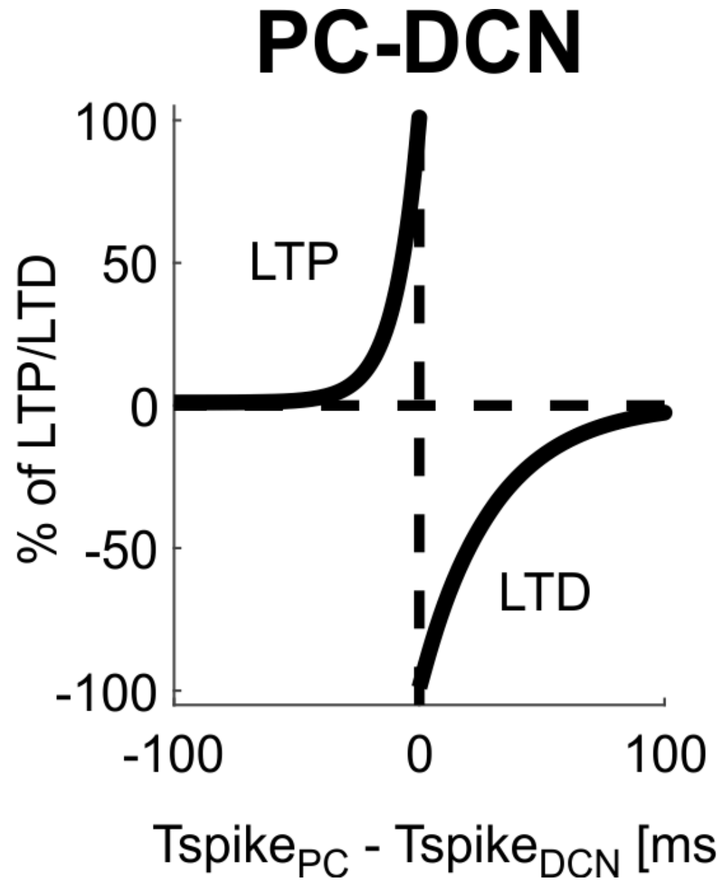
Physiological Background: the Plasticity







[Carrillo et al., 2008; Garrido et al., 2013; Kleberg et al., 2014]

Physiological Background: the Functionality

Cerebellum is the **most plastic neural structure** in the brain and has a critical role in adaptive motor control by implementing three fundamental operations:

- Prediction
- Timing
- Learning

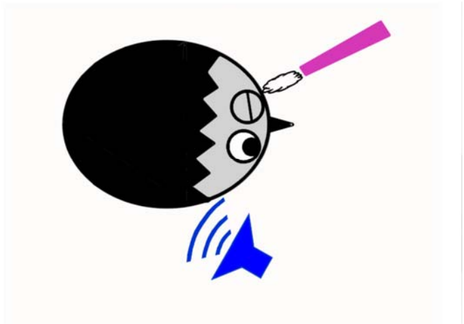
[D'Angelo and Casali, 2012, D'Angelo et al., 2013]

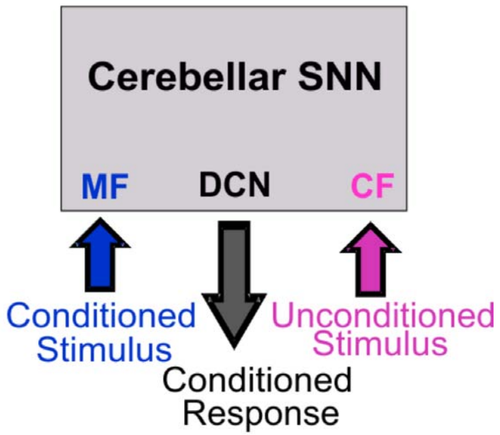
Motor control protocols where the cerebellum is critically involved:

- Eye Blink Classical Conditioning (EBCC) *[Medina et al., 2000; Bracha et al., 2000]*
- Vestibulo-Ocular Reflex (VOR) *[Ito, 1982]*
- Limb movements perturbed by Force Fields (FF) *[Donchin et al., 2012]*

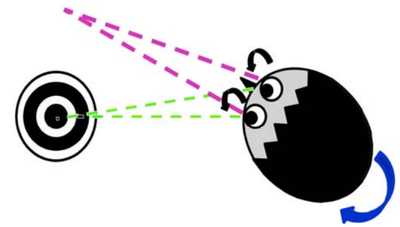
Robotic Embodiment of the Cerebellar Models

Eye Blink Classical Conditioning (EBCC)

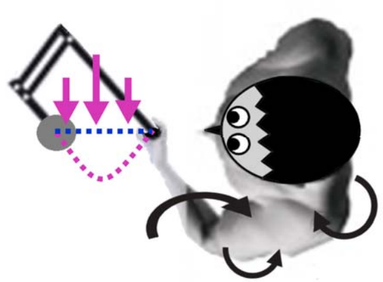




Vestibulo-Ocular Reflex (VOR)



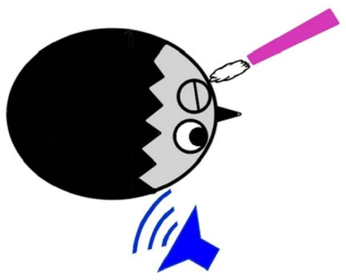
Movements perturbed by Force Fields (FF)



[Casellato et al., 2014]

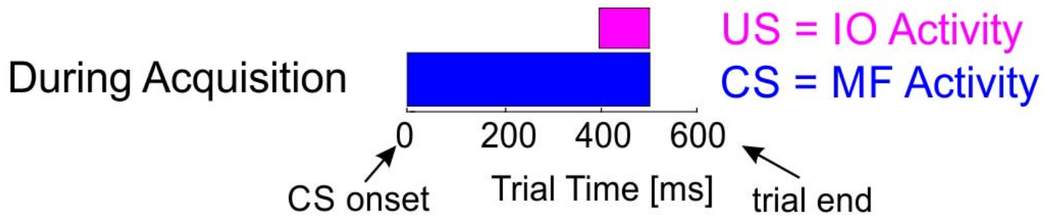
Physiological Models of the Cerebellum: Paradigm

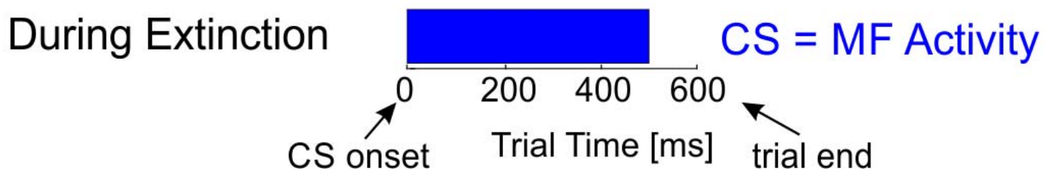
EBCC
(EyeBlink Classical Conditioning)



Unconditioned Stimulus (US)
Airpuff → Start of CF activity

Conditioned Stimulus (CS)
Tone → Start of MF activity





Conditioned Response (CR), anticipating US
Anticipated blink and reduced US sensation

2 sessions of 100 Trials
80 Trials of Acquisition + 20 Trials of Extinction

Physiological Models of the Cerebellum: Results

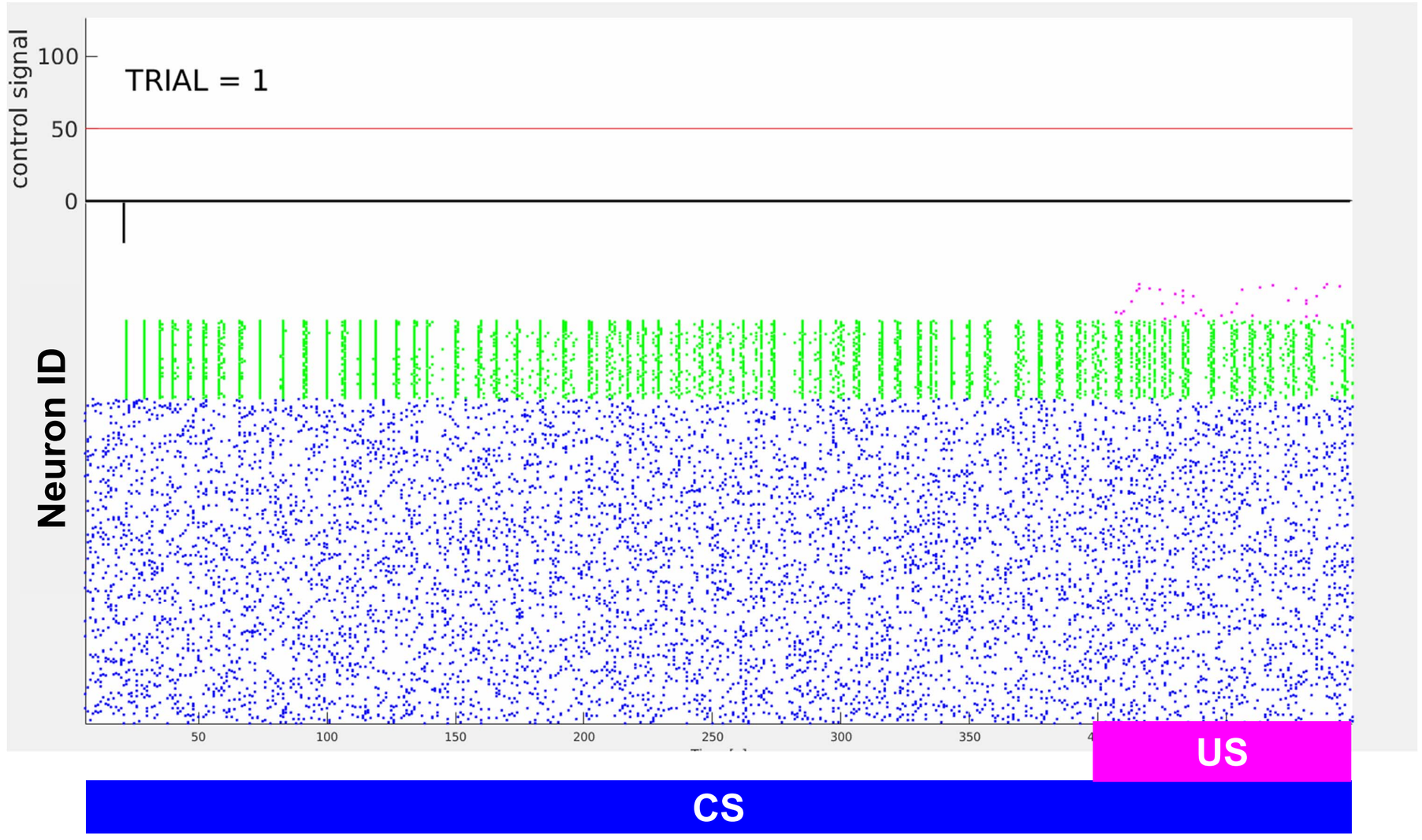
CR threshold
Eyelid closure

DCN: Decoding the motor output

IO: Encoding the US (Air puff)

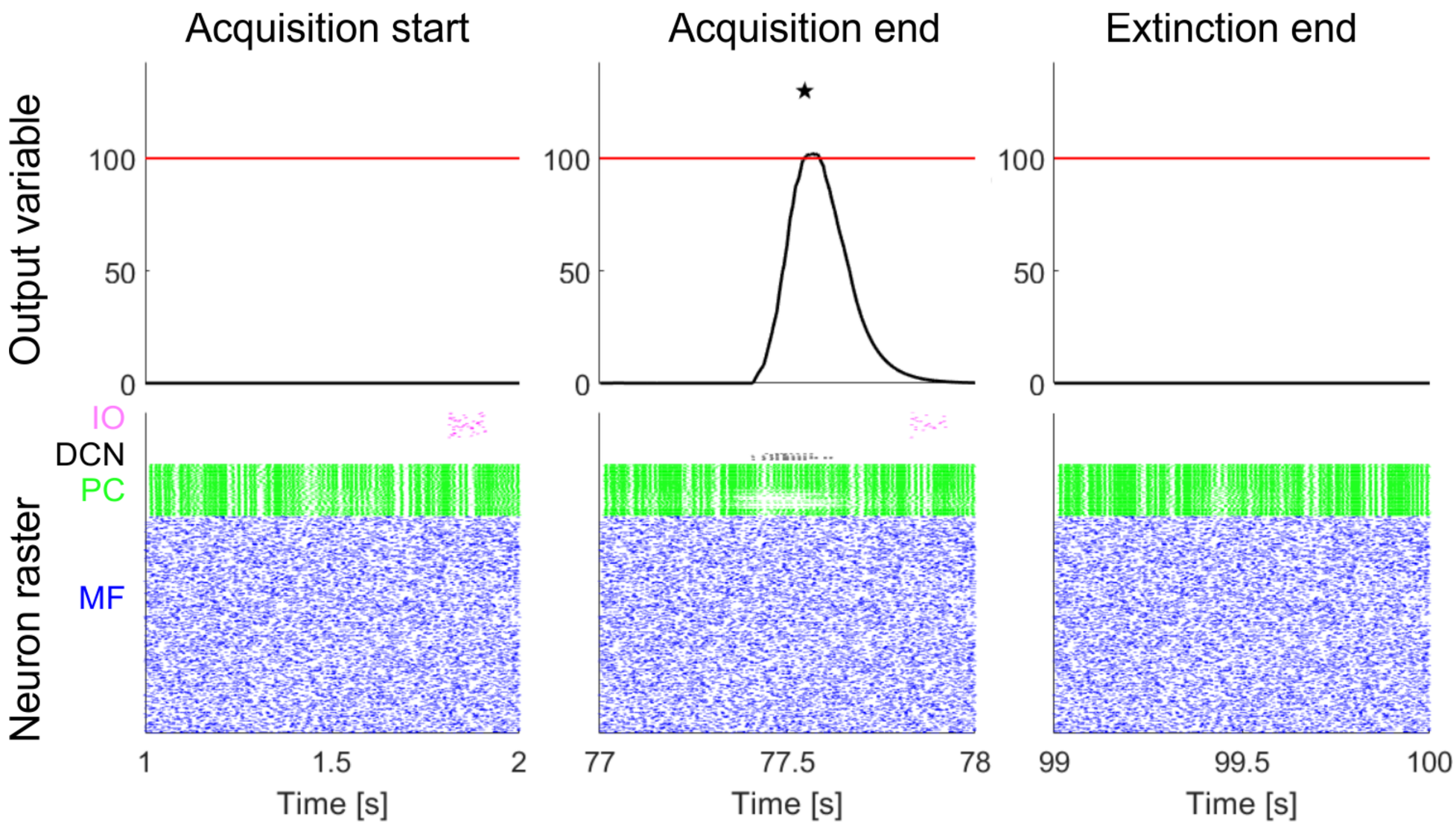
PC: activity modulated trial-by-trial

MF: their activity encodes the CS (Tone)

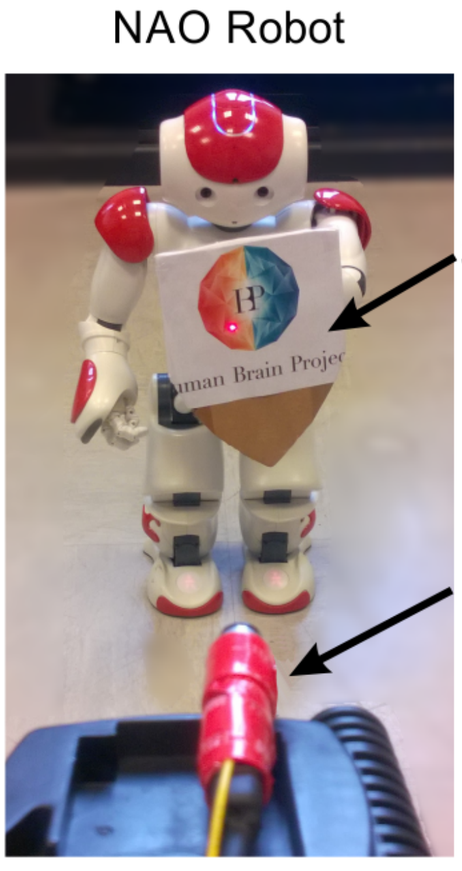


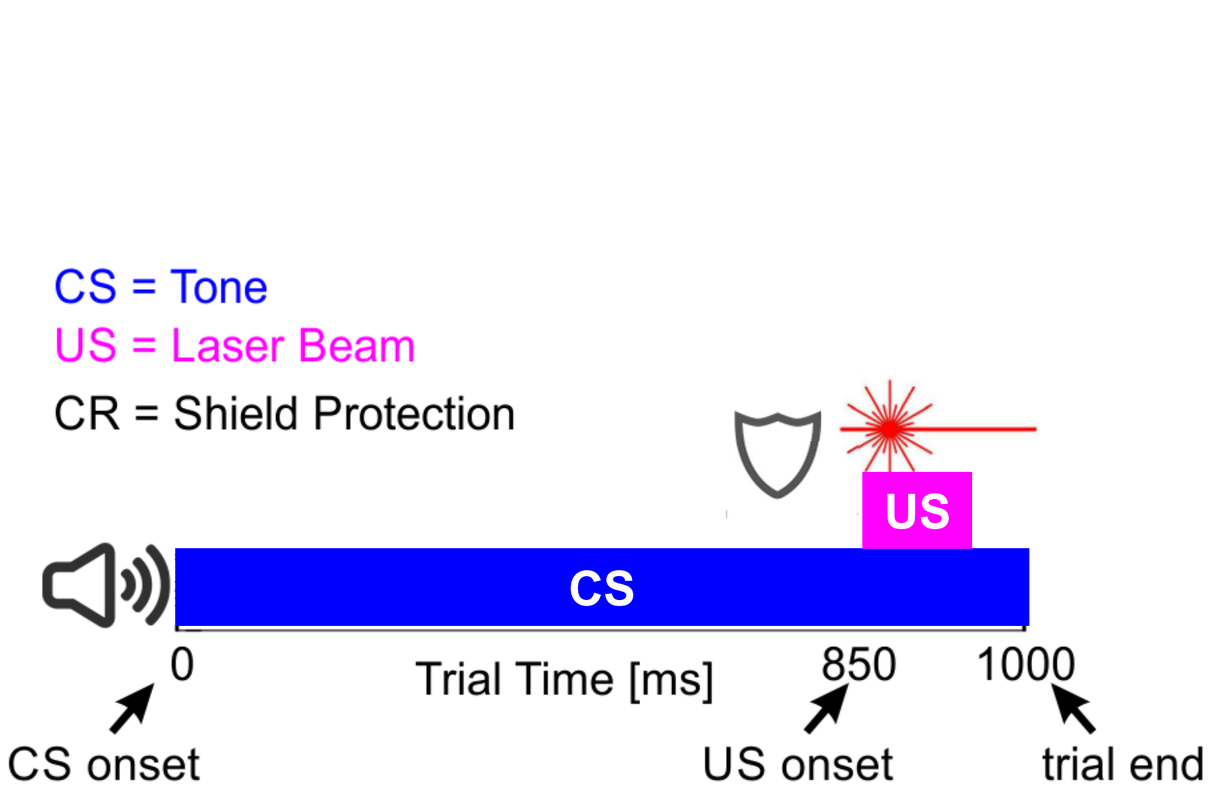
Trial Time [each trial = 500 ms]

Physiological Models of the Cerebellum: Results



EBCC with NAO Robot





[Antonietti et al., 2018]

Robotic Embodiment of the Cerebellar Models: EBCC with NAO Robot

https://www.youtube.com/watch?v=57stDA5zU3Q

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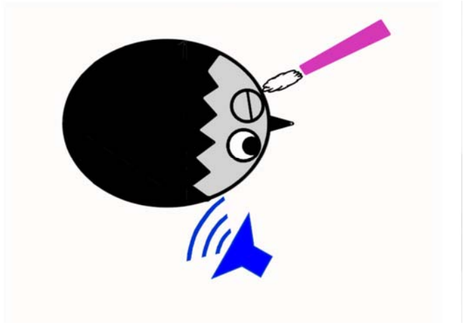
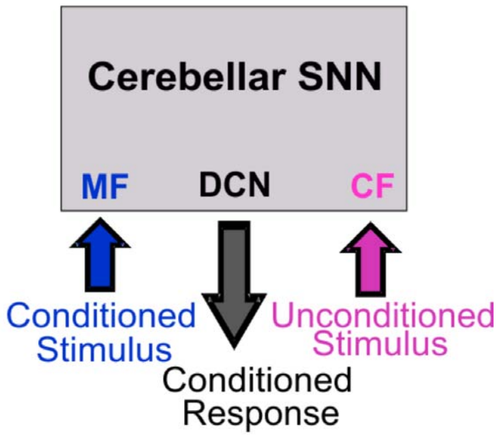
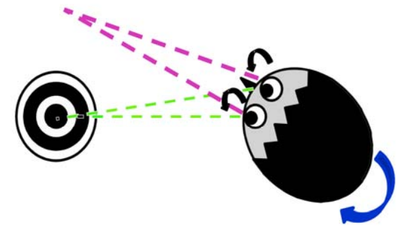
Robotic Embodiment of the Cerebellar Models

Eye Blink Classical Conditioning (EBCC)

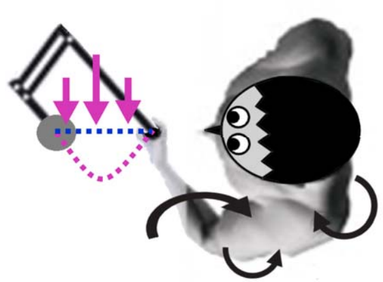




Vestibulo-Ocular Reflex (VOR)

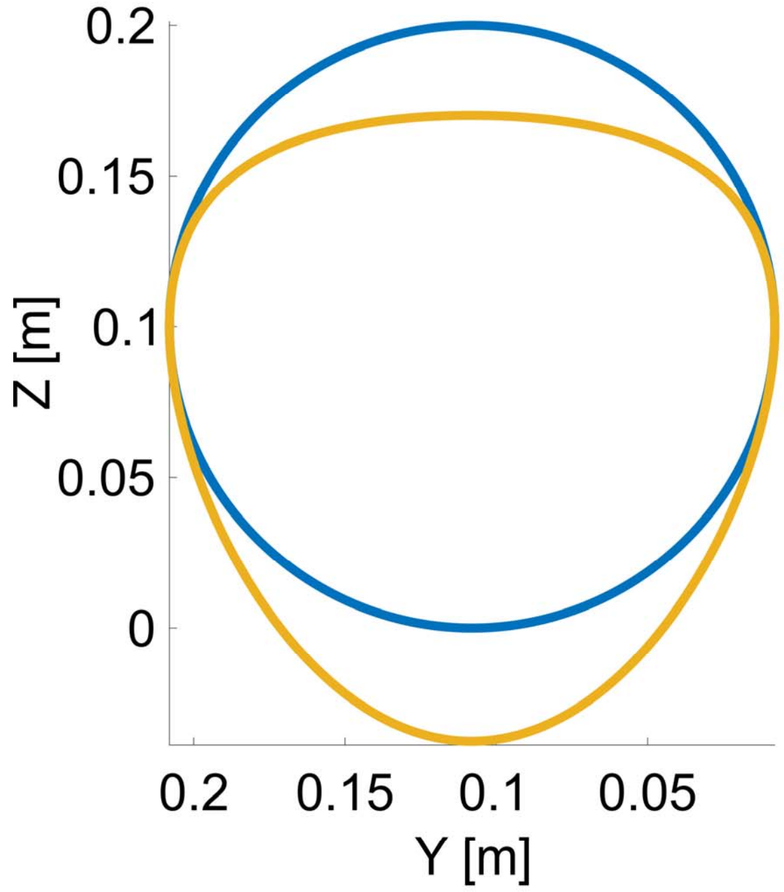


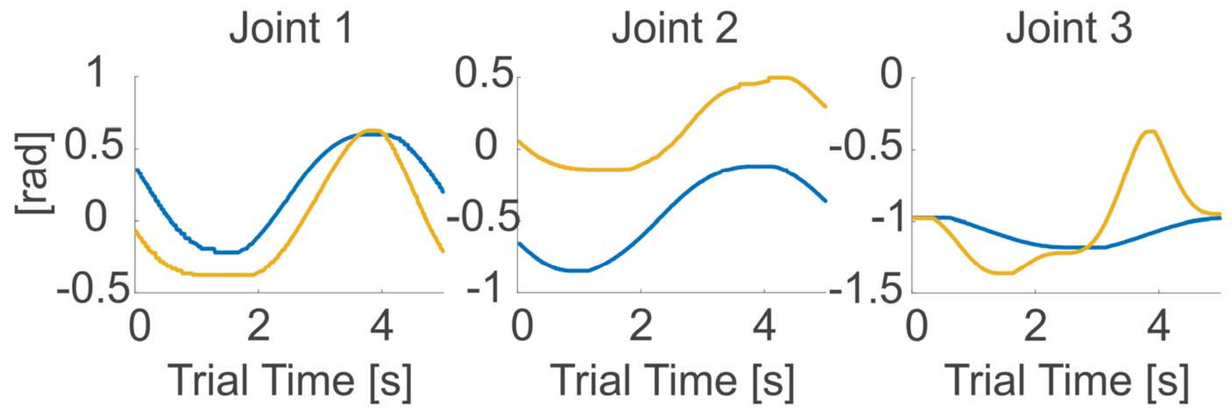
Movements perturbed by Force Fields (FF)

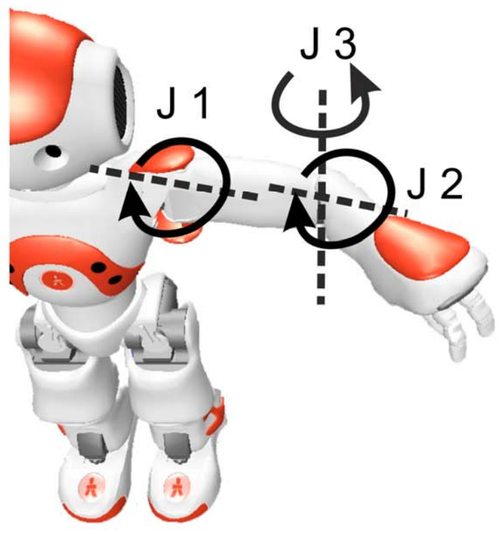


[Casellato et al., 2014]

Robotic Embodiment of the Cerebellar Models: FF with NAO Robot







Joint 1 = Shoulder Pitch
(Shoulder Elevation)

Joint 2 = Elbow Yaw
(Humeral Rotation)

Joint 3 = Elbow Roll
(Elbow flex-extension)

[Antonietti et al., 2019]

Robotic Embodiment of the Cerebellar Models: FF with NAO Robot

https://www.youtube.com/watch?v=5KpCEO0GCjc

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How can we deal with heavier simulations?

- Point-neuron simulator
- Physics simulator
- Robot controller
- Experiment pipeline
- Interface layer

nest :: simulated()

PyNN

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Caveats from my (limited) experience

- If default models are used, you can leverage the online platform, the container (Docker) or the live USB image.
- Other cases require to build NRP from source (quite tricky)
- Install it on a VM or, better, a dedicated partition/disk.
- For local simulations, keep the complexity of the network and robotic environment at low levels.

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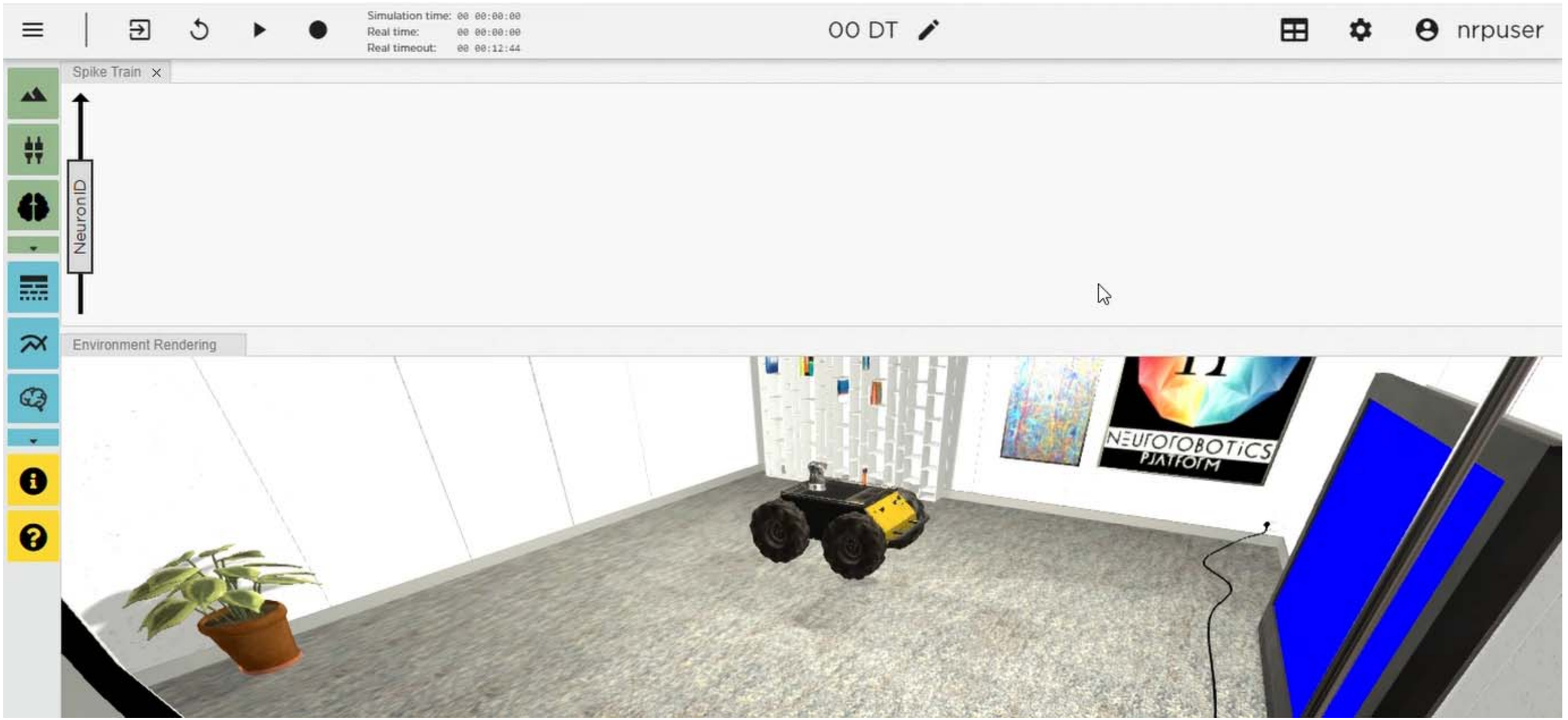
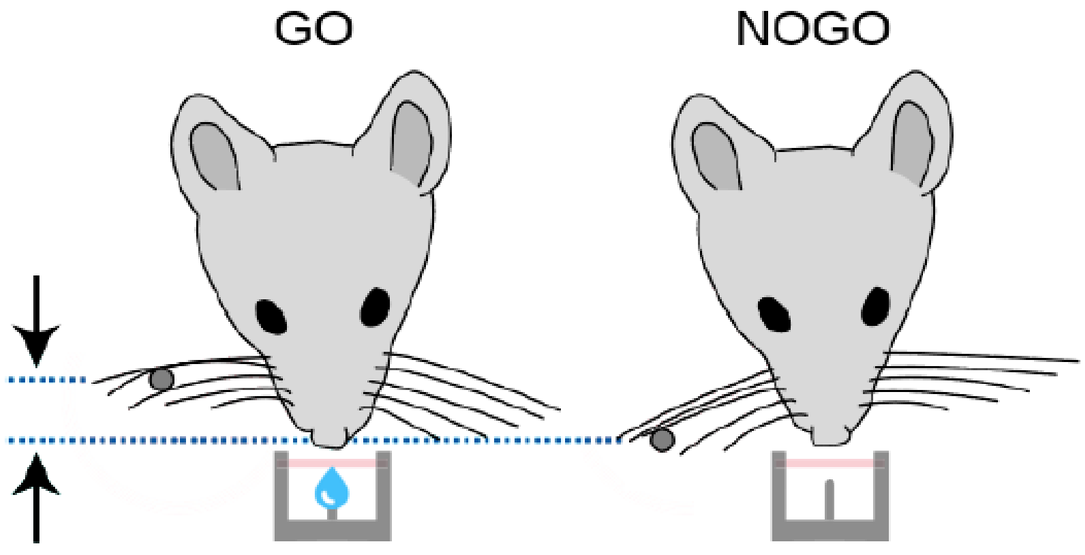
NRP in action: parking-sensor cerebellum

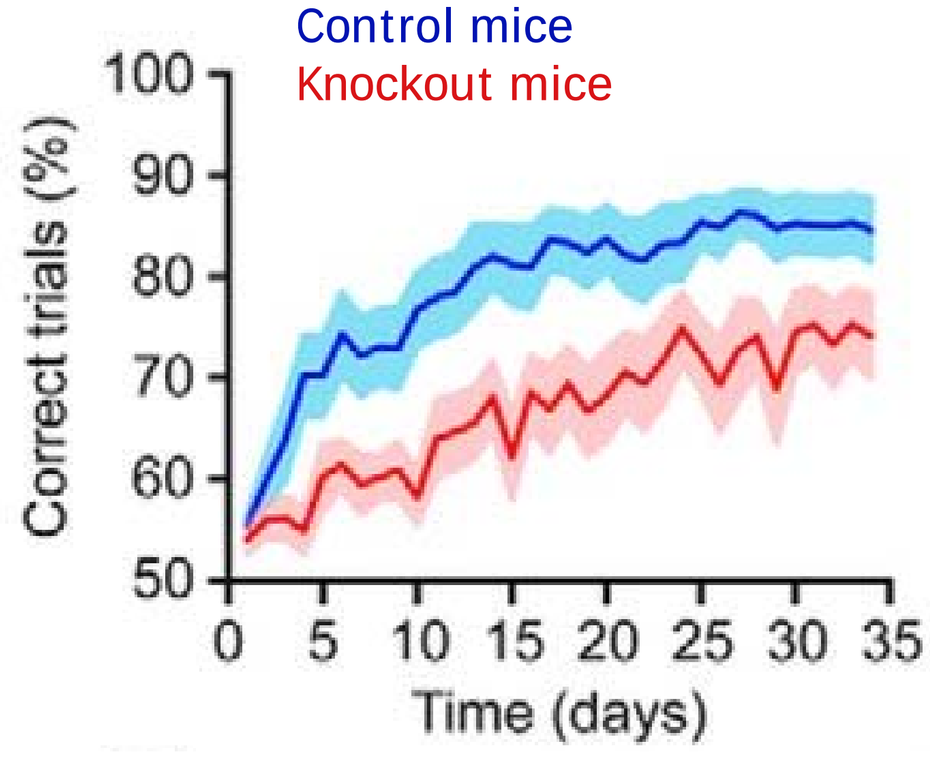


[Negri and Trapani, work In progress!]

NRP in action: mouse whisking

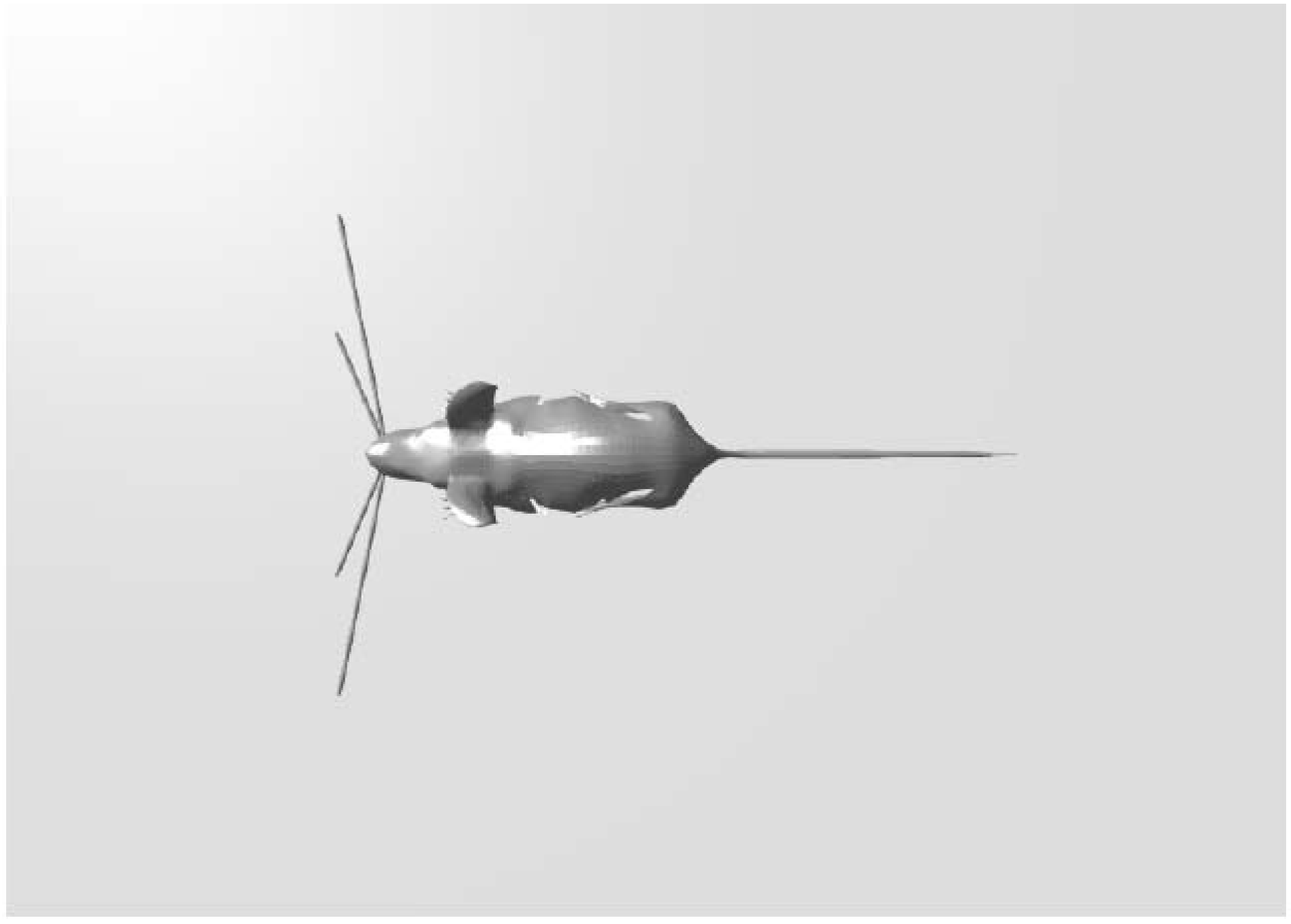
Cerebellar Potentiation and Learning a Whisker-Based Object Localization Task with a Time Response Window





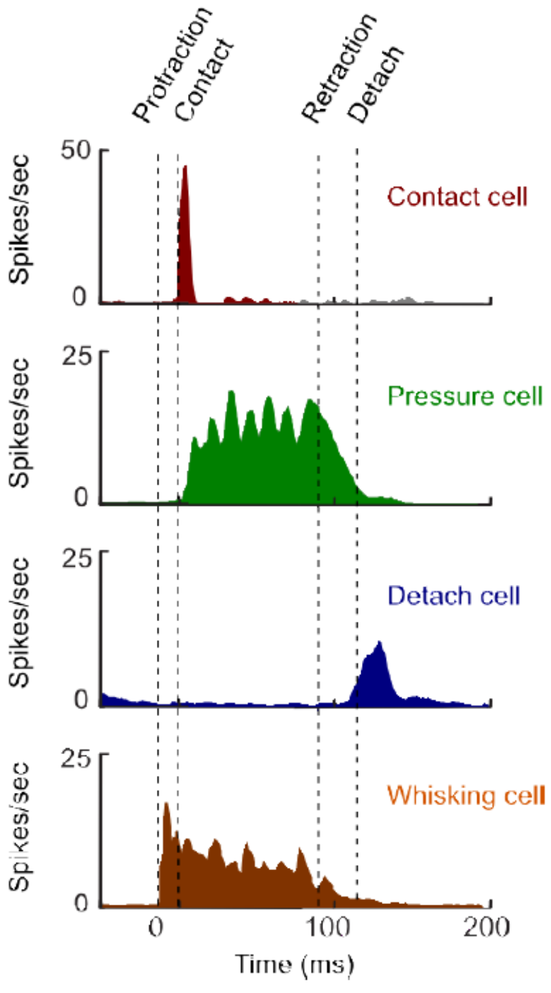
[O'Connor et al., 2010; Rahmati et al., 2014]

NRP in action: mouse whisking



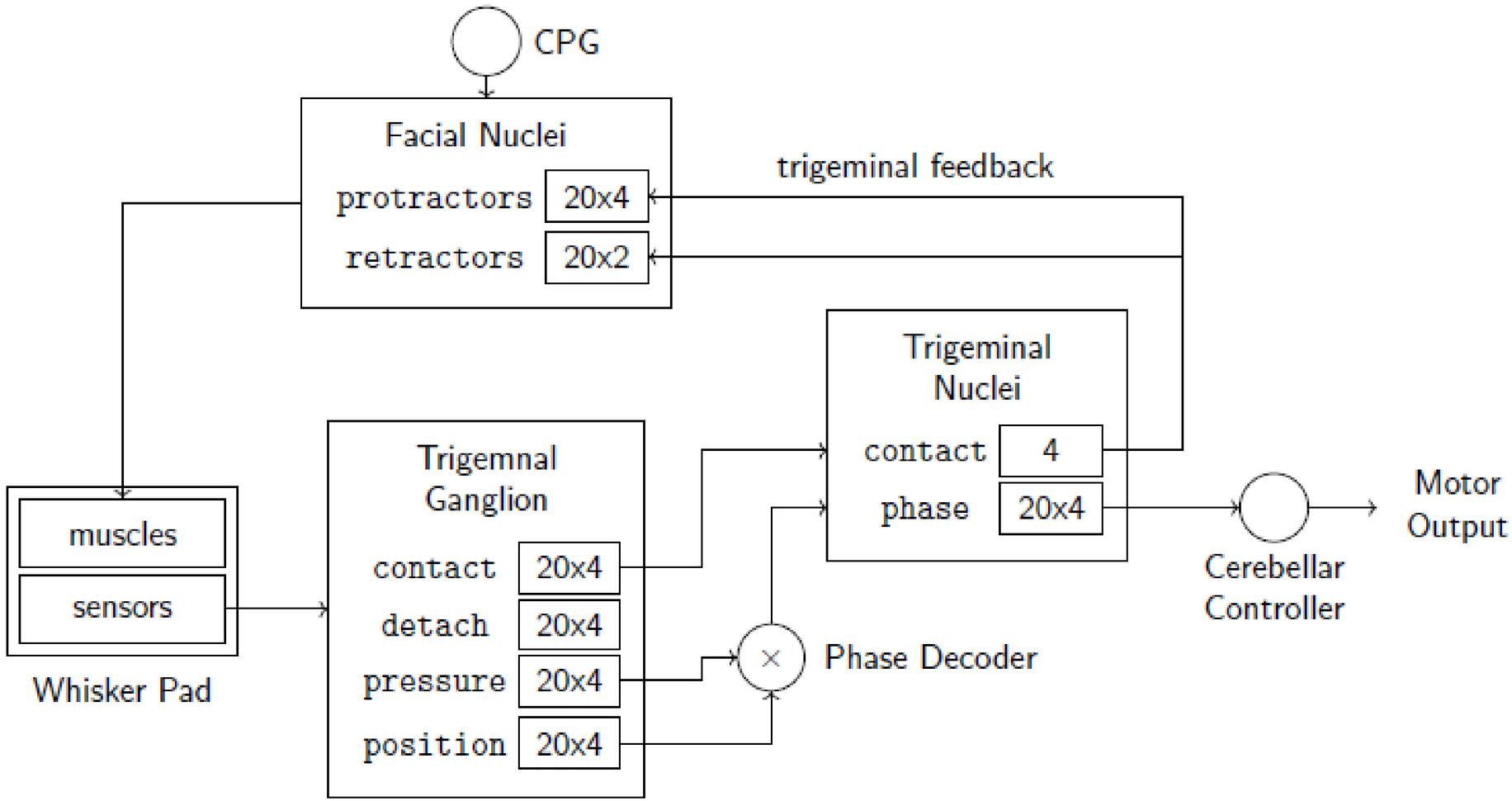
Mouse model with four controllable whiskers

[Edoardo Negri, MSc Thesis 2019]



[Ahissar et al, 2011]

NRP in action: mouse whisking



[Edoardo Negri, MSc Thesis 2019]

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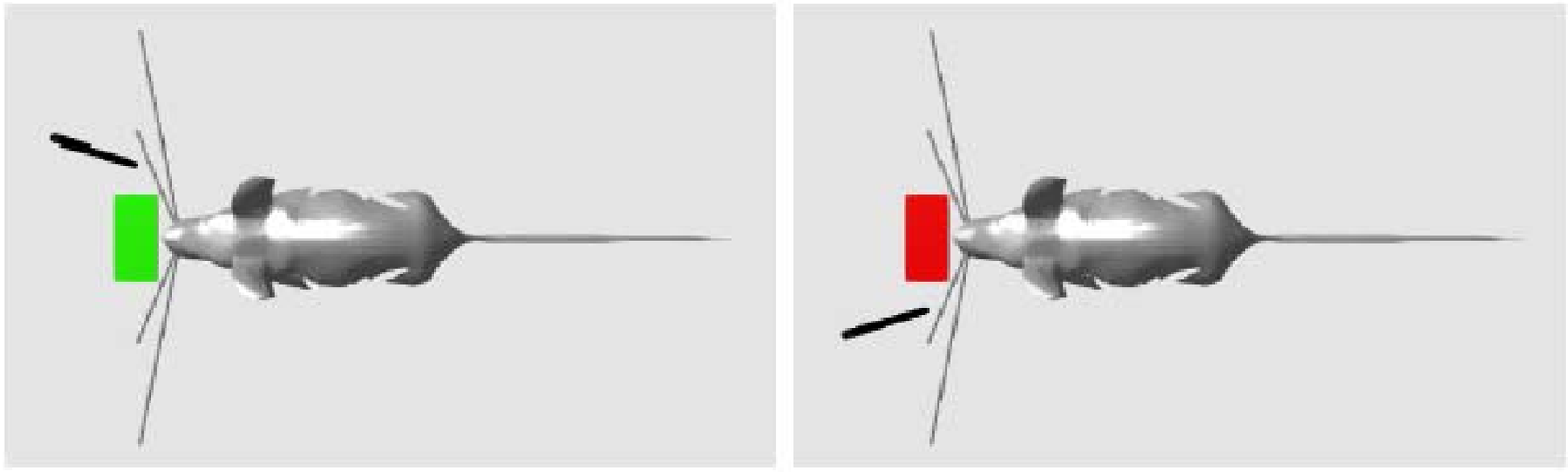
NRP in action: mouse whisking

- Instead of licking the virtual mouse moves its head to hit a support above the snout, receiving or not a reward
- 2 seconds trials, grouped in sessions by 10 trials each, 5 GO and 5 NOGO, performed in a randomized sequence

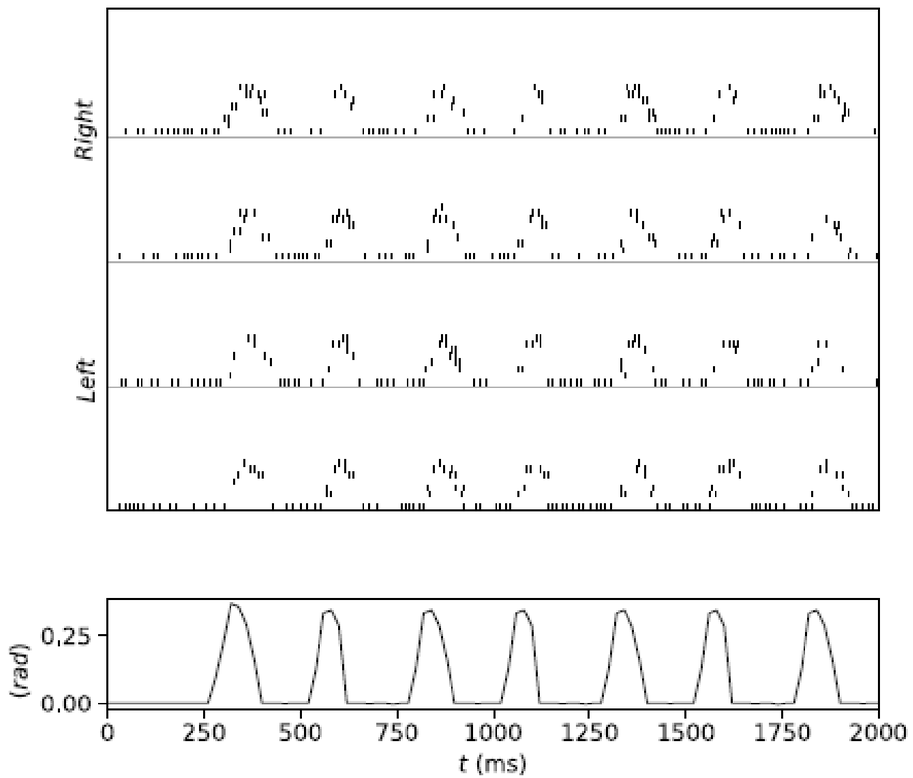


Whisking mouse in the NRP during a GO and NOGO-trial

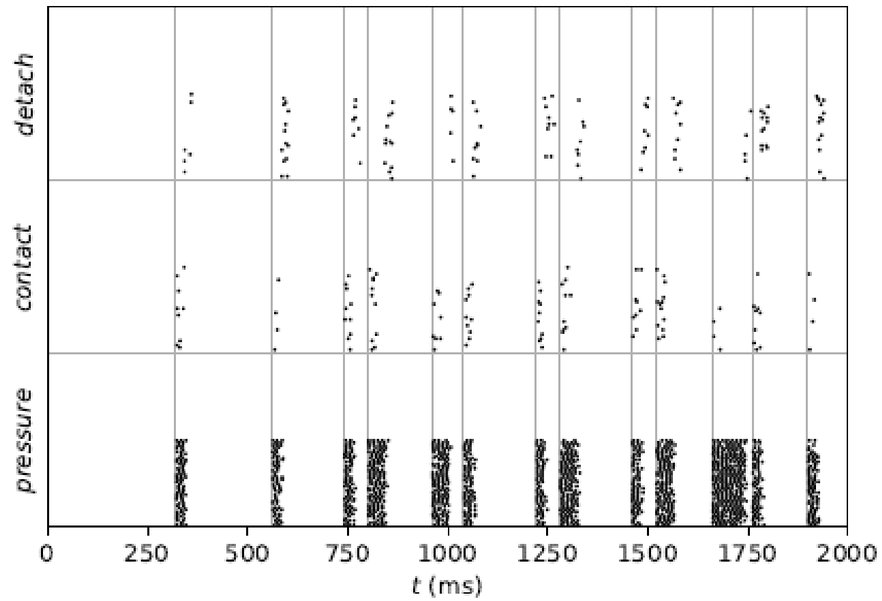
[Edoardo Negri, MSc Thesis 2019]

NRP in action: mouse whisking

Whisker Position Cells



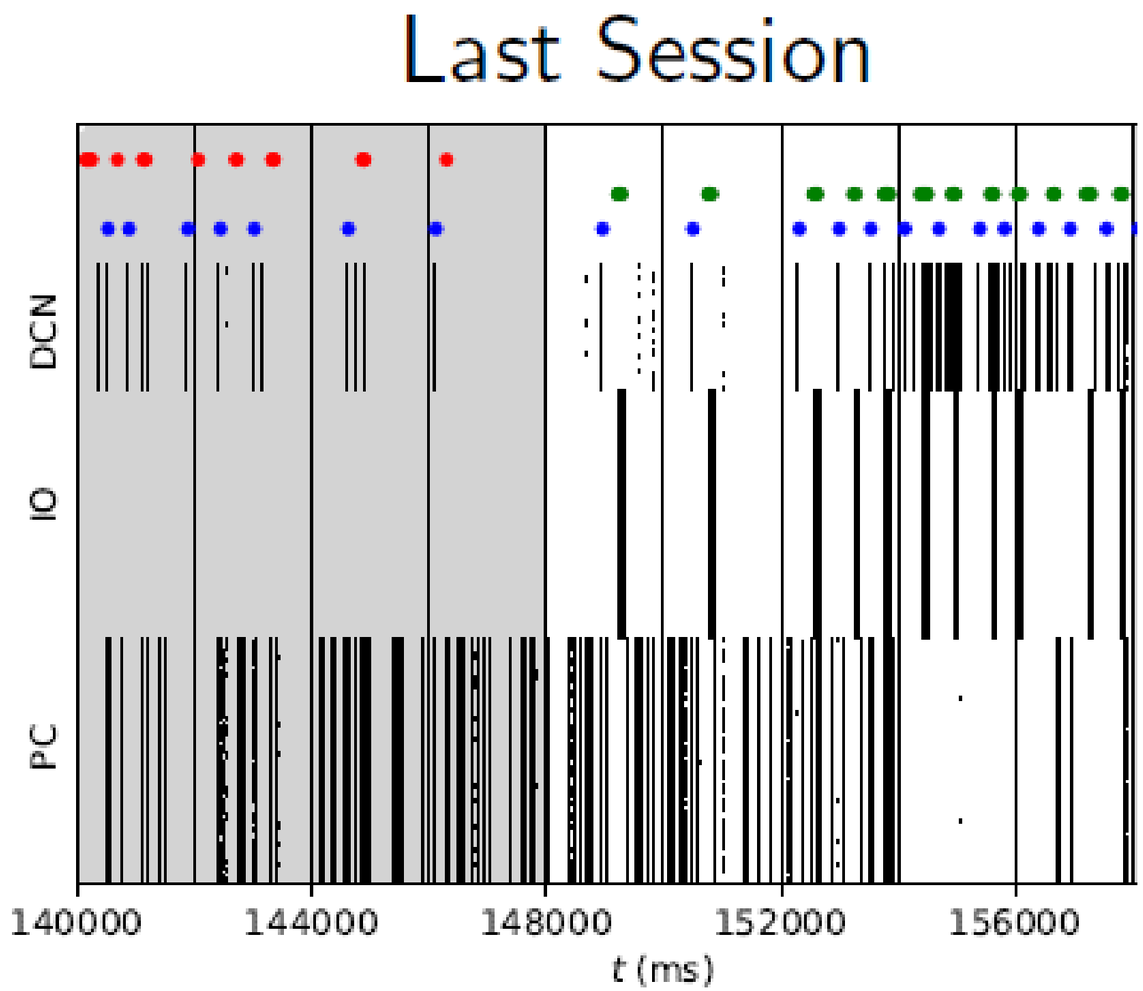
Trigeminal Ganglion during contact



On the left whisking cells during free whisking compared to actual whisker position. On the right trigeminal ganglion activity during contact

[Edoardo Negri, MSc Thesis 2019]

NRP in action: mouse whisking



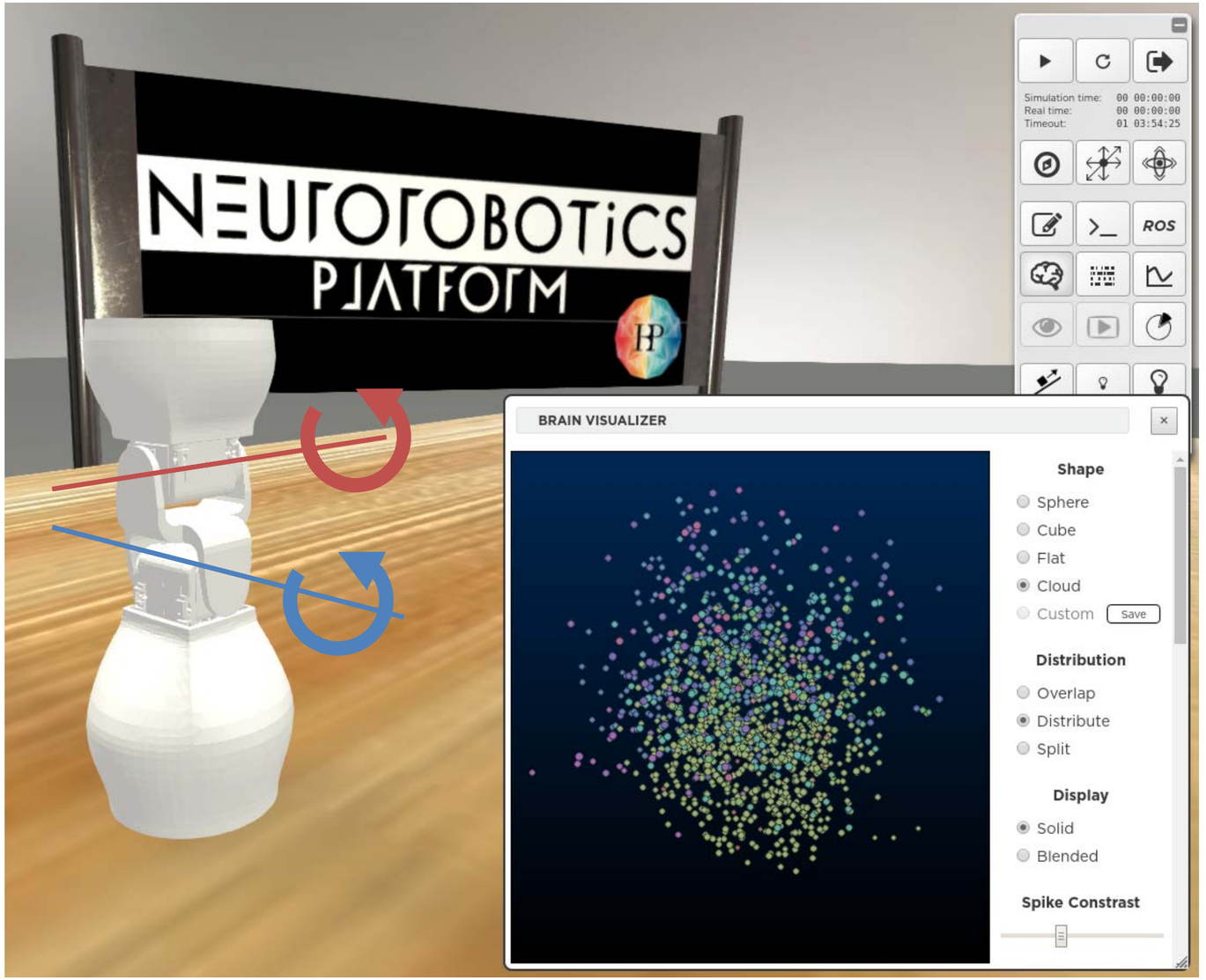
[Edoardo Negri, MSc Thesis 2019]

GO trial | NOGO trial | Rise head signals | Rewarded hits | Not rewarded hits

NRP in action: fine motor correction

$$y_0 = A \cdot \sin(\pi \cdot t)$$

$$y_1 = A \cdot \sin(\pi \cdot t + \theta)$$



[Corchado et al., 2019]

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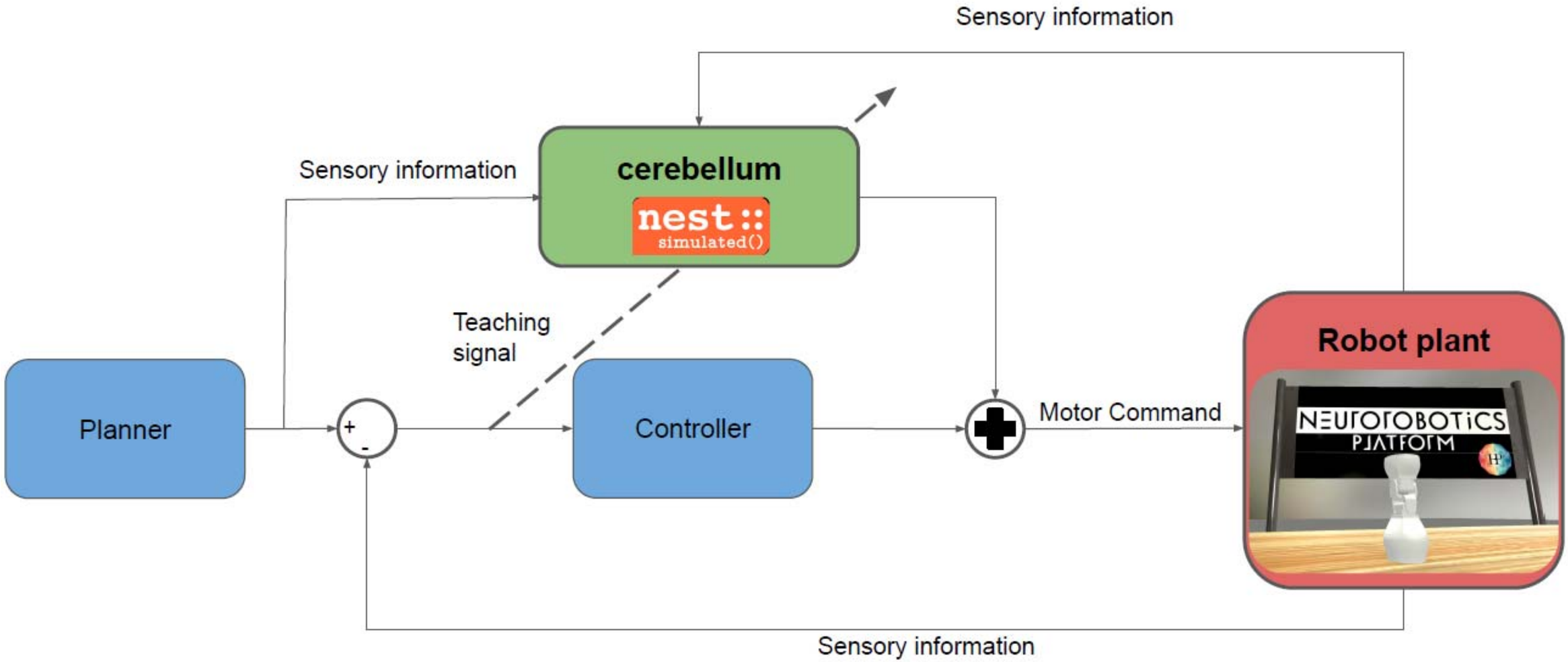
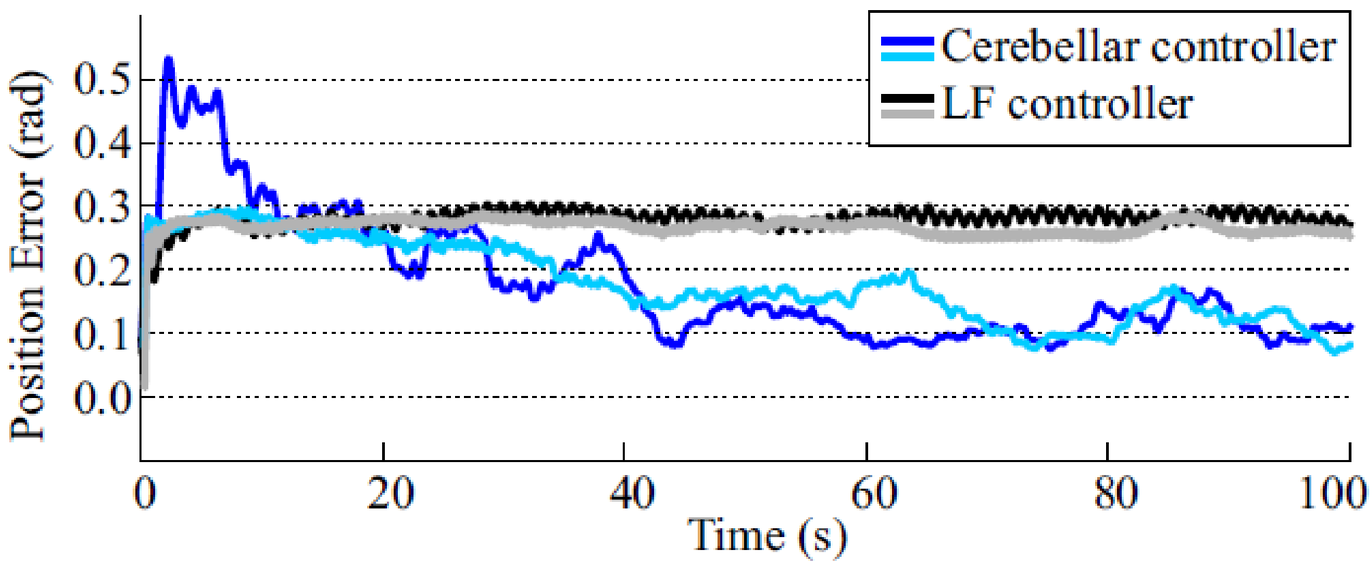
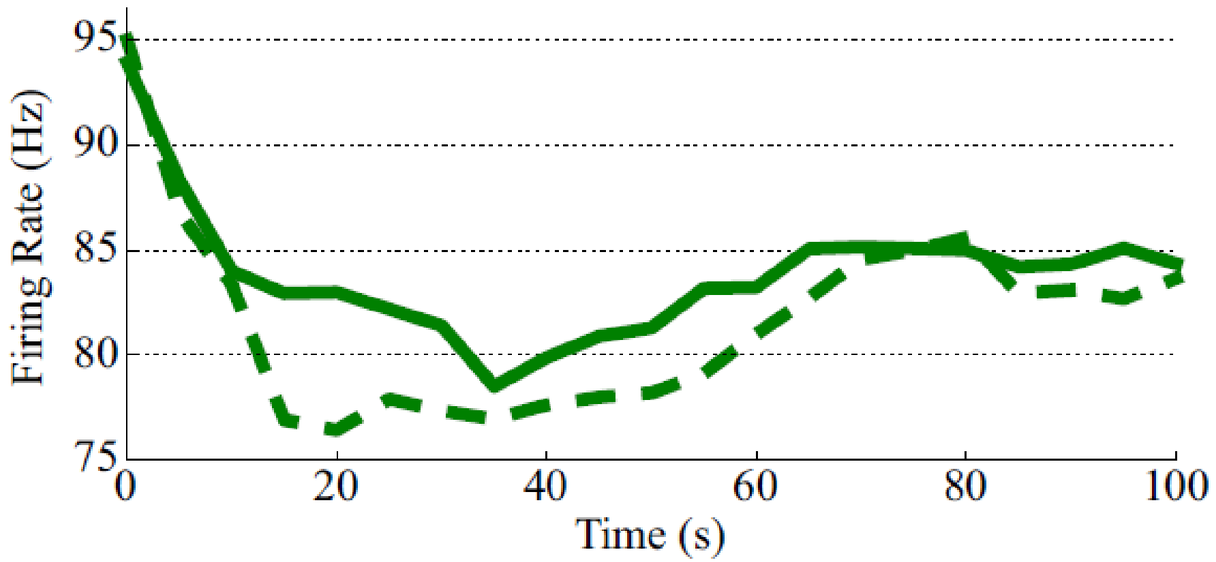
NRP in action: fine motor correction



NRP in action: fine motor correction





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What's next?

- Parallel NRP

- Integration with HPC

- Larger networks

- More complex paradigms

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Human Brain Project

Thank You

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