SUNY Downstate Medical Center

Large-scale M1 microcircuit model with plastic input connections from biological PMd neurons used for prosthetic arm control

NEUROSIM LAB

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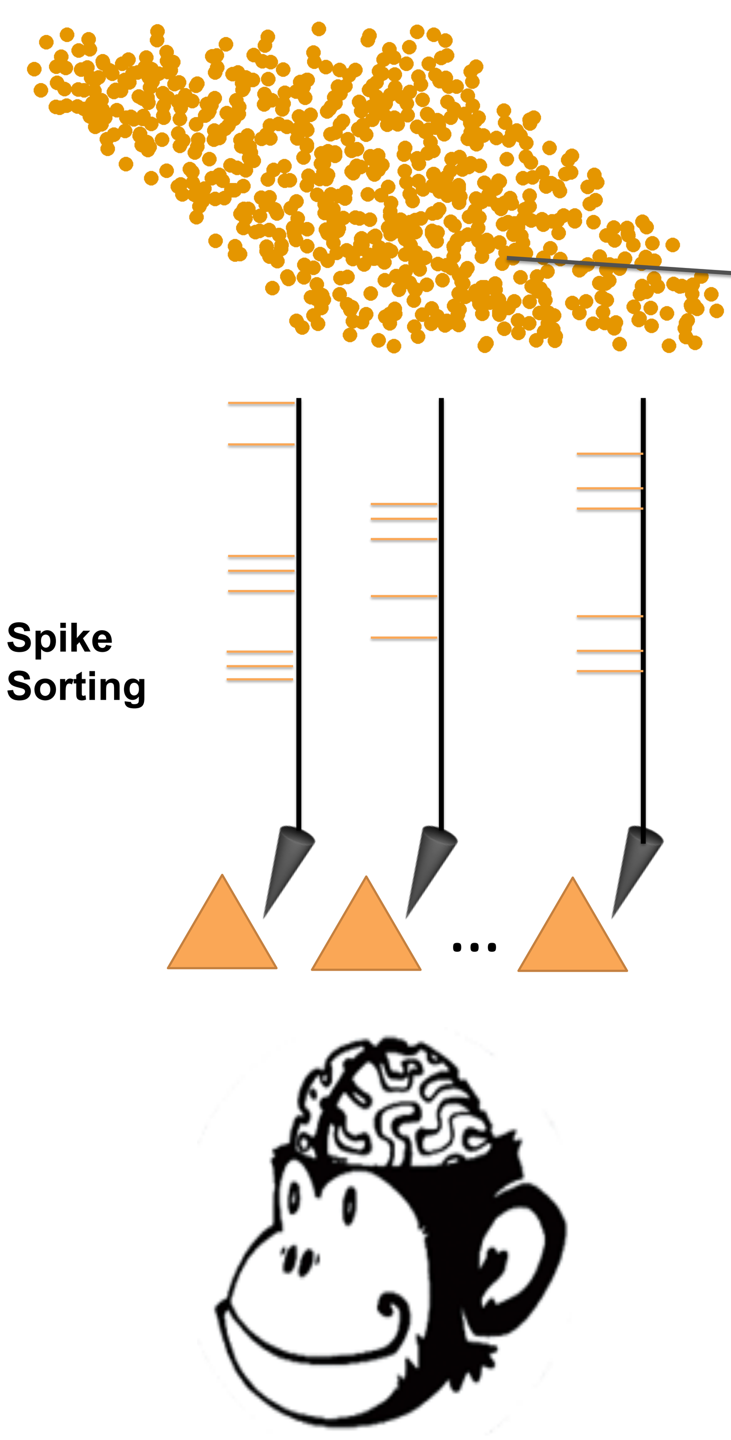
Summary

- Biomimetic spiking model of M1 and spinal cord drives virtual musculoskeletal arm and robot arm.
- M1 model is modulated by activity recorded from macaque PMd neurons during reaching.
- System trained via reinforcement learning and STDP to learn to reach 2 targets; plasticity between several populations including PMd biological neurons and M1 model neurons..
- After training, PMd input determines the virtual arm trajectory (target to reach).
- Moves towards a new generation of neuroprosthetic systems where biological brain circuits interact directly with multiscale biomimetic cortical models.
- Future applications in neuroprosthetic control (BMI), or to replace/repair damaged cortical regions.

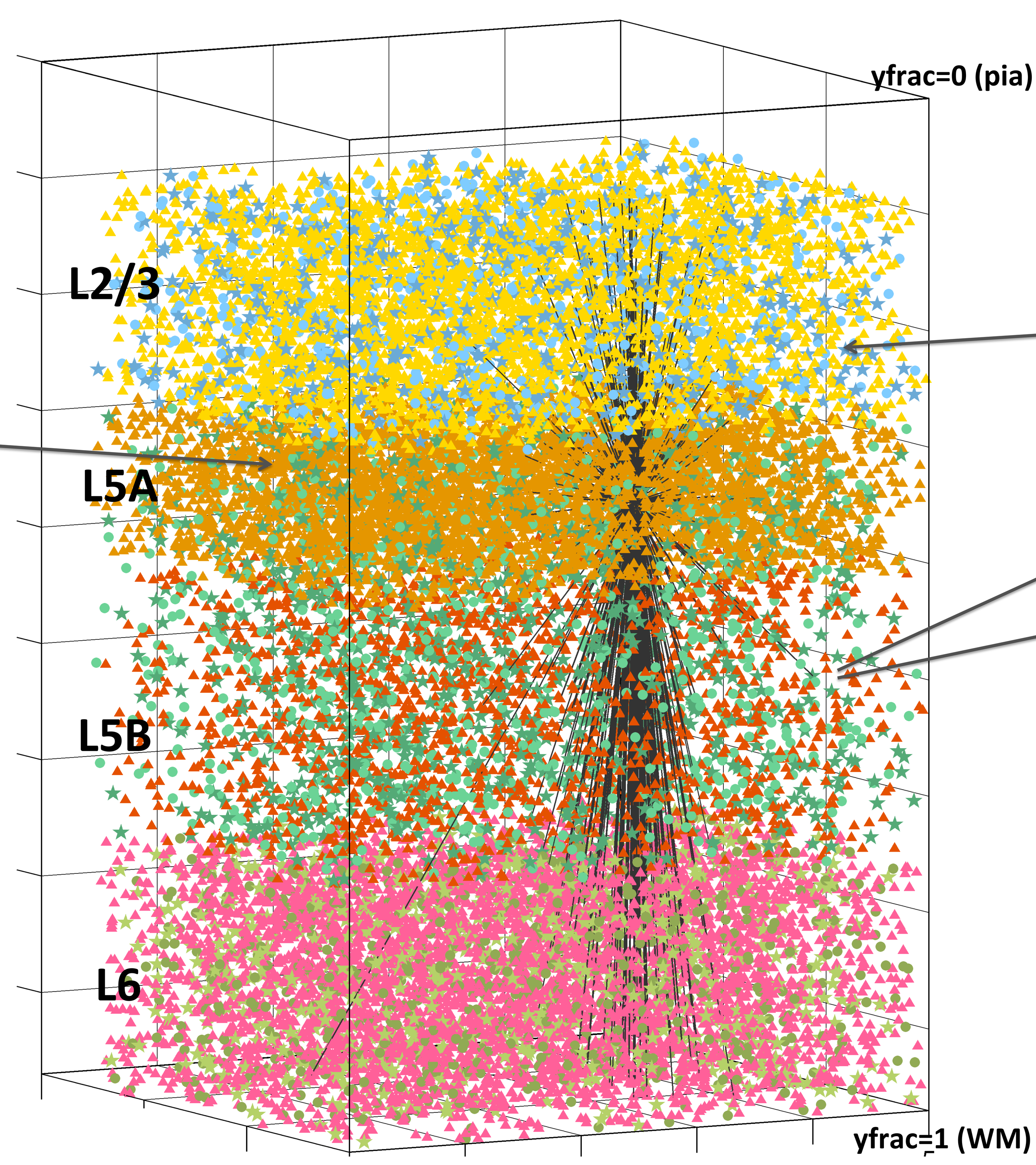
Model Description

- M1 microcircuit model (L2/3, L5A, L5B, and L6) with realistic connectivity (NEURON-based).
- 8,000 spiking neurons (Izhikevich) of 3 cell types: excitatory pyramidal cells, fast-spiking and low-threshold spiking inhibitory cells; and 4 types of synaptic receptors: AMPA, NMDA, $GABA_A$ and $GABA_B$.
- ~500k synaptic connections; ~200k plastic connections.
- Ascending spinal cord population receives arm proprioceptive info and projects to M1 L2/3.
- Desceding spinal cord populations: receive input from M1 L5B, and calculates arm muscle excitation; Inh cells project to antagonistic muscle Exc cells.

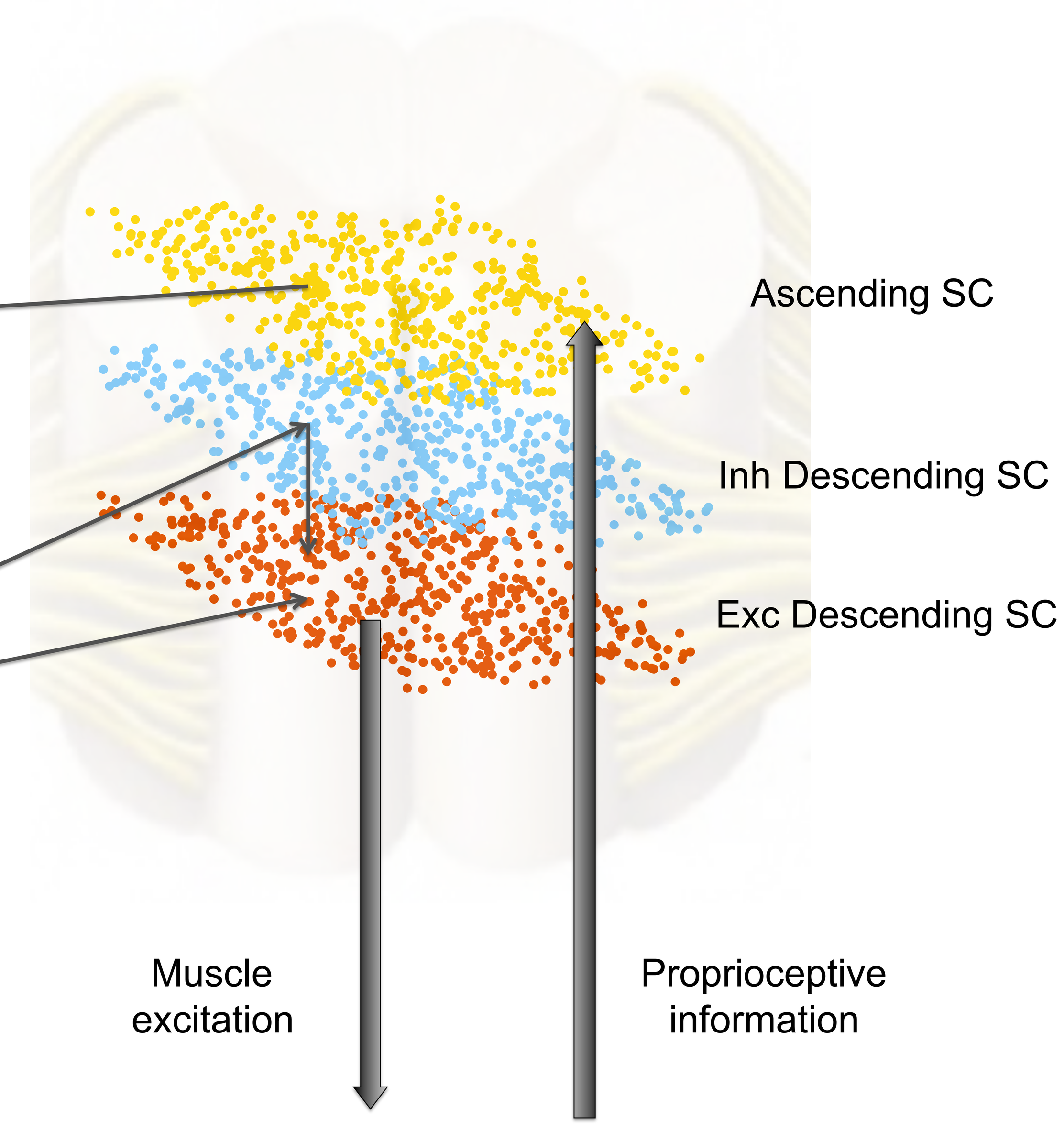
Premotor cortex (PMd) biological neurons

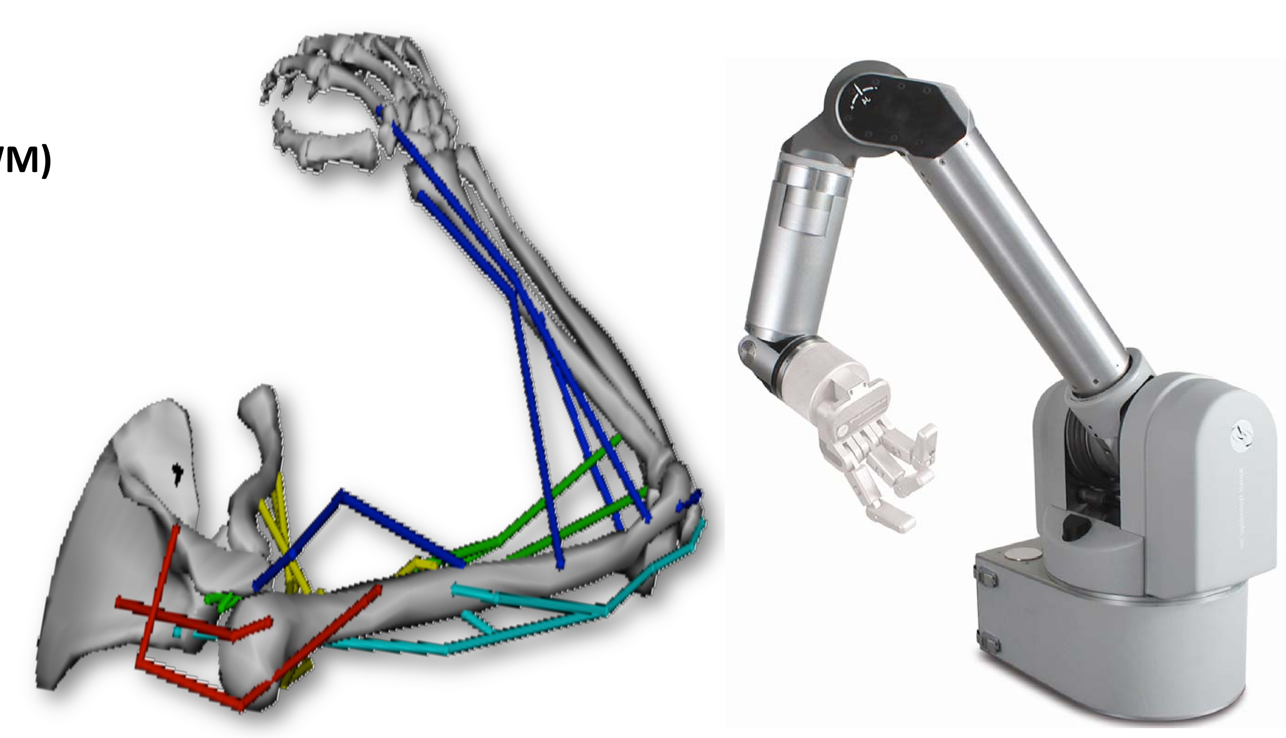


Primary motor cortex (M1) model



Spinal cord model

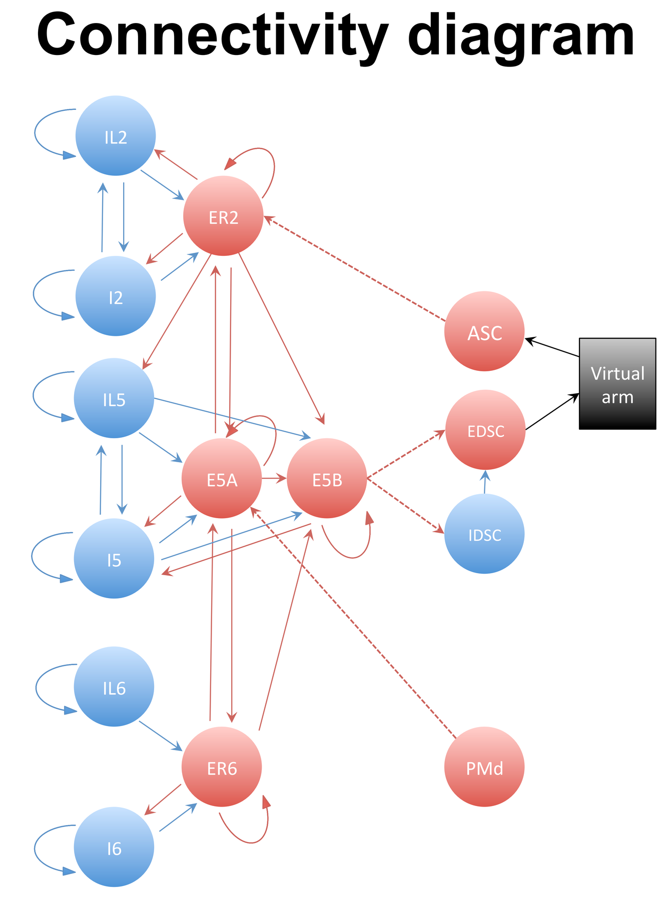




Extracellular recordings (in vivo)

- Activity from 96 PMd biological neurons was recorded during a center-out reaching task to left and right targets.
- PMd spike patterns were replicated using NEURON VecStims and provided input to M1 L5A excitatory population (randomly connected).
- Plexon-recorded multiunit activity can be used as input to a NEURON model in real time.

Connectivity diagram



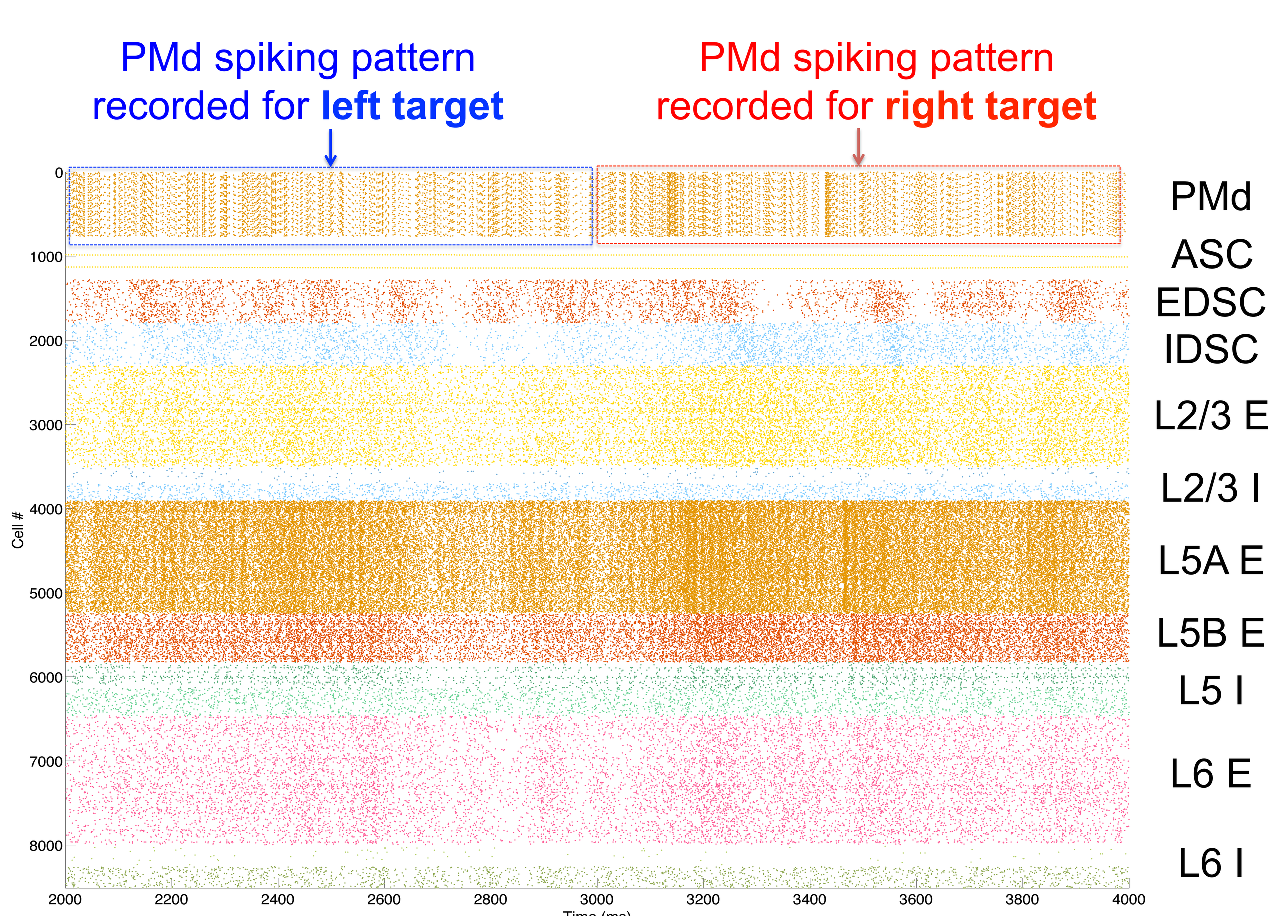
red = excitatory; blue = inhibitory
dotted lines = plastic connections

Virtual/Robot arm

- Includes 8 rigid bodies, 7 joints, 14 muscle branches divided into 4 muscle groups, leading to 2 degrees of freedom
- Extended Hills muscle model: force depends on current muscle length, velocity and activation. Activation is delayed response (ODE) to the neural excitation input.
- Every time step, given input muscle excitation, model calculates muscle activation, fiber and tendon lengths, force, contraction velocity, and position and velocity of each of the joints.
- Robot arm reproduces virtual arm trajectory in real time.

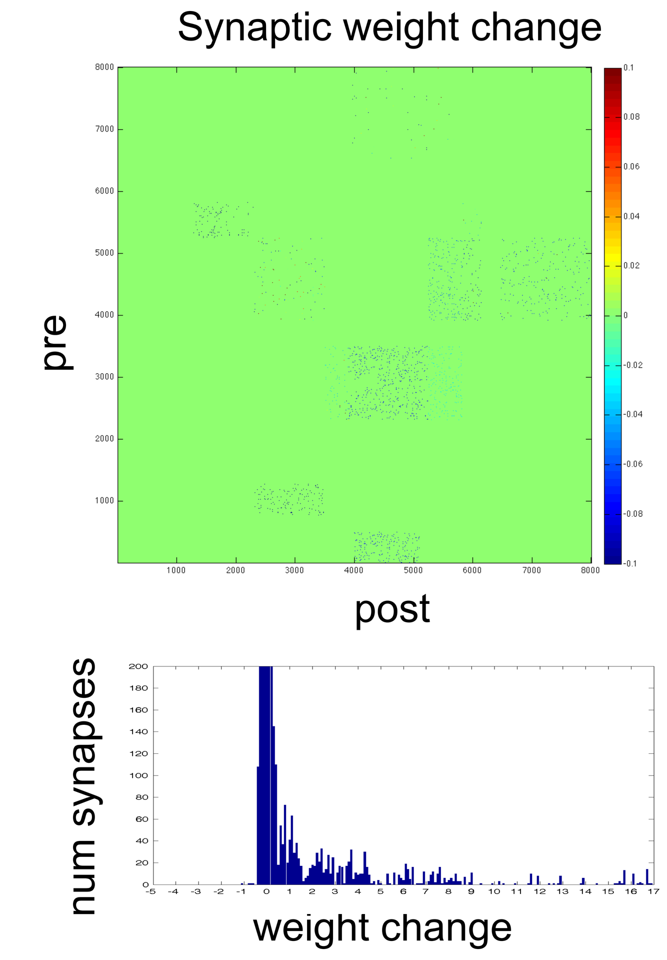
Training via reinforcement learning

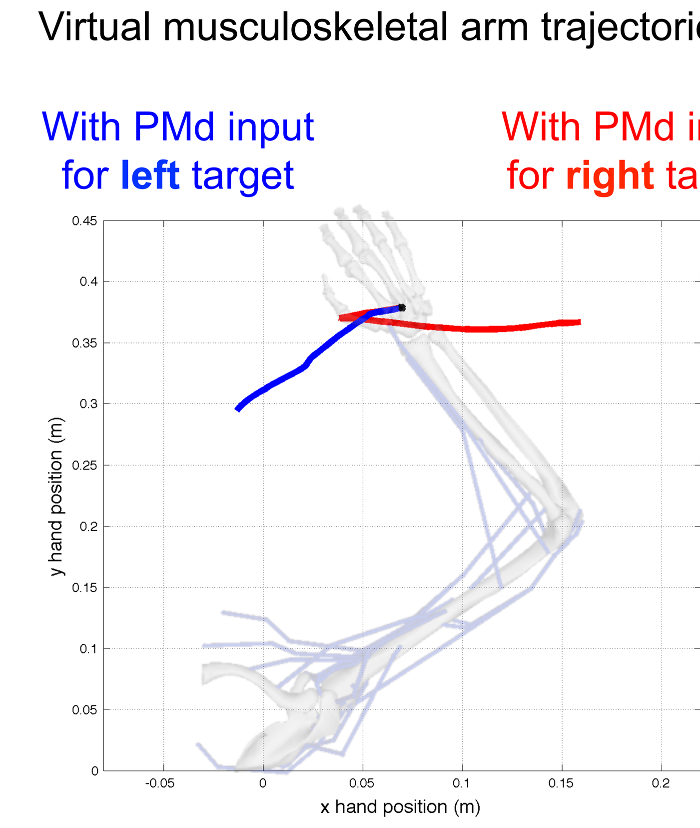
- STDP, reinforcement learning (+ eligibility traces), and arm exploratory movements were used to train the network to reach 2 targets.
- If hand got closer to target, relevant synapses were potentiated (reward); if got farther, synpases were depressed (punish).
- During training, the rewarded target and the PMd input were switched every 1 second, in order to associate each PMd pattern to one target.
- Evolutionary algorithms were used to optimize the learning metaparameters (eg. learning rate).



- Raster plot showing alternating training to left vs right target (rewarded target and PMd input pattern switch every sec)

After Training





- After training, input PMd acitivity determines the virtual arm direction

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