Skill learning and modeling sensorimotor circuits

Mathis Group for Computational Neuroscience and AI

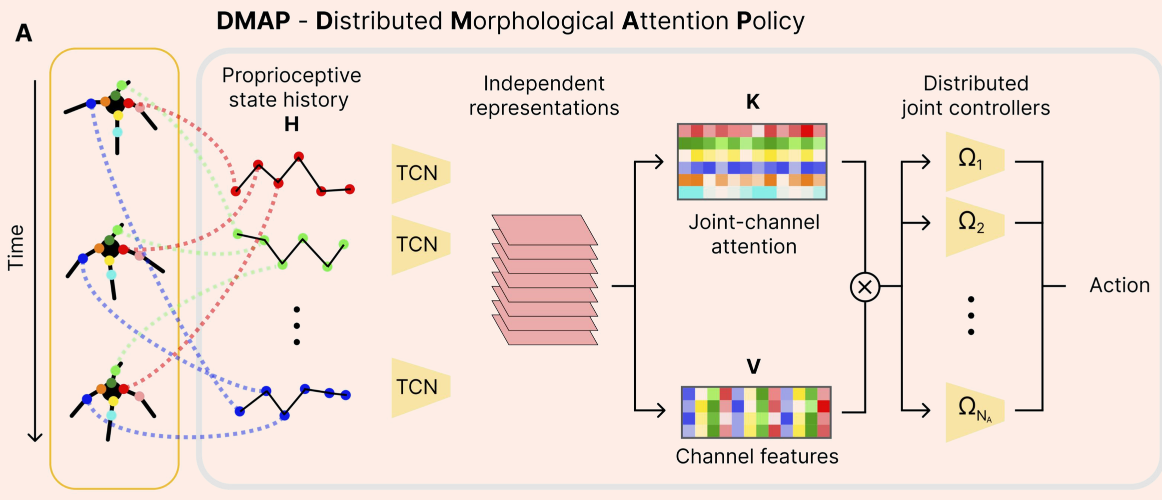
We develop **normative theories** of **neural systems** that are trained to perform **sensorimotor behaviors** as well as **task-driven models.**

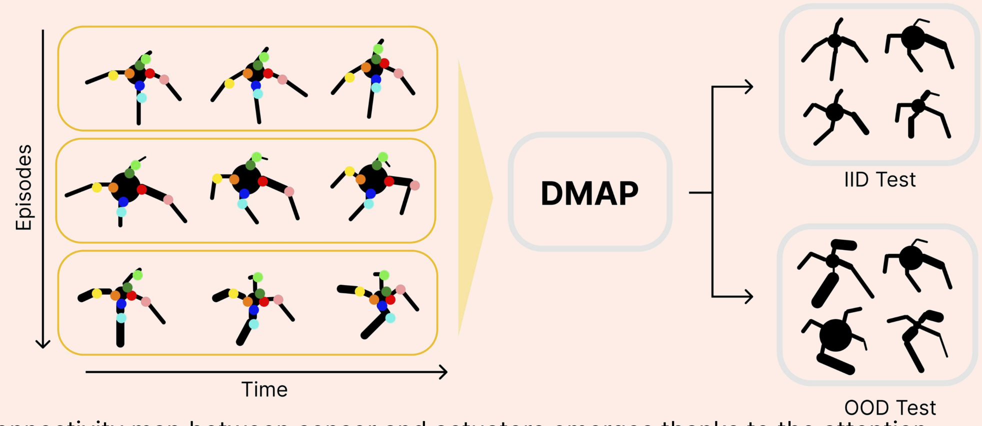



Join **us and Mackenzie Mathis' lab** in Geneva!

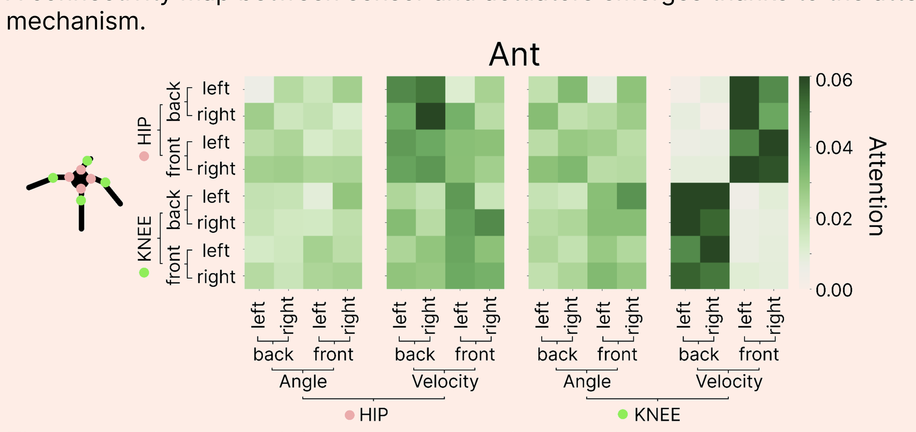
DMAP: a policy architecture for adaptive locomotion

DMAP processes past sensory information to develop a representation of the current state of the body. In this way, it can learn to control agents with variable body shapes.

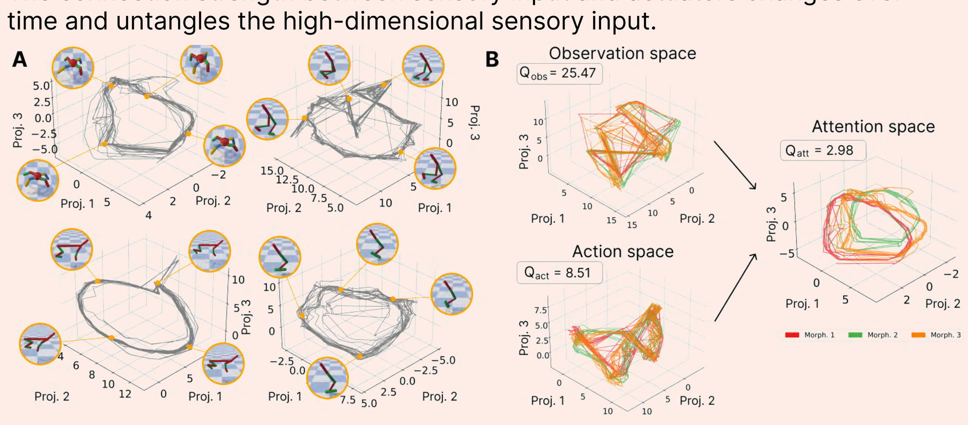




A connectivity map between sensor and actuators emerges thanks to the attention mechanism.



The connection strength between sensory input and actuators changes over time and untangles the high-dimensional sensory input.



Chiappa, A., Marin Vargas, A., and Mathis, A. "DMAP: a Distributed Morphological Attention Policy for learning to locomote with a changing body". NeurIPS, 2022.

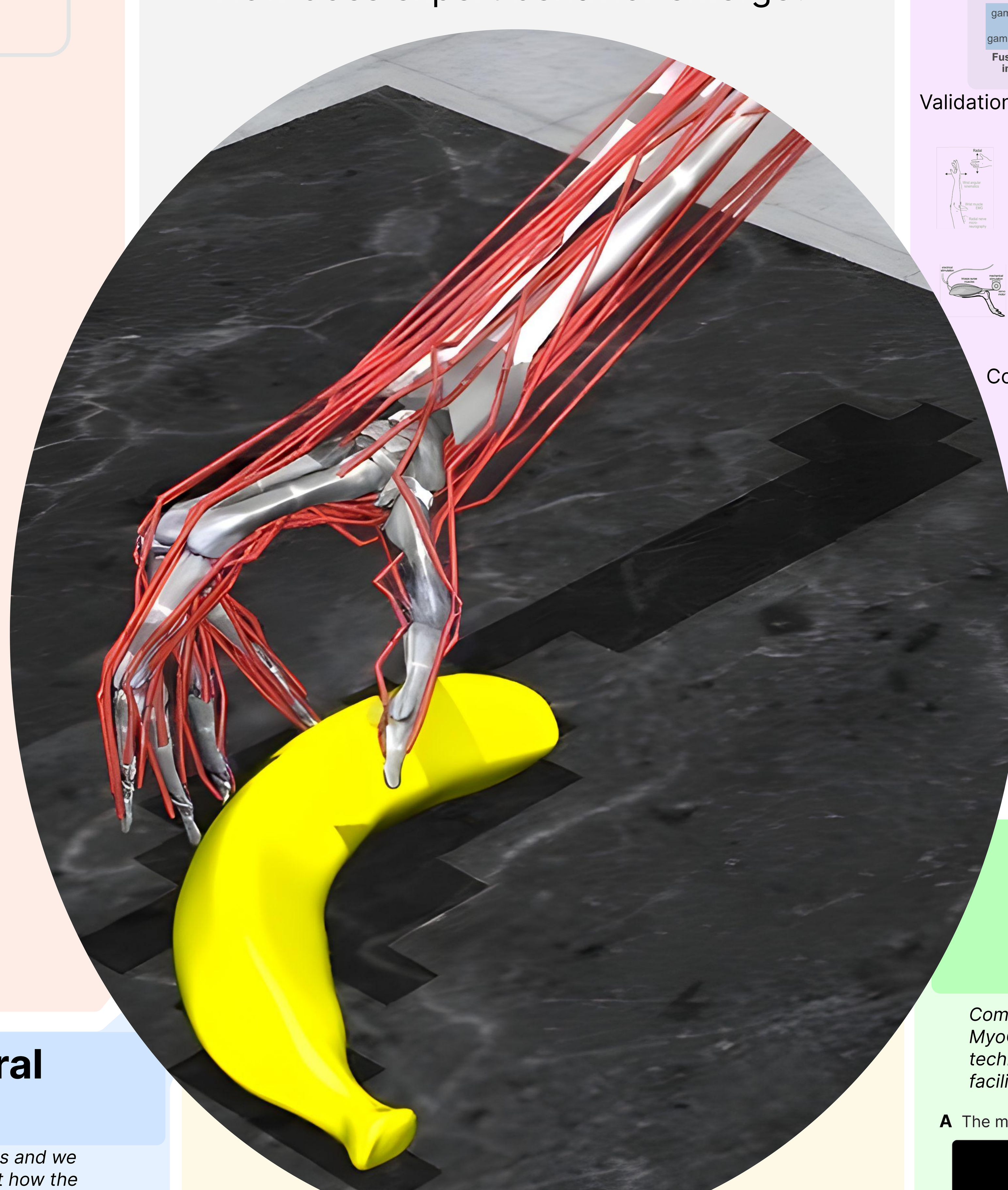
RESEARCH QUESTIONS

What are the principles of proprioception?

What are the neural mechanisms underlying robust motor control?

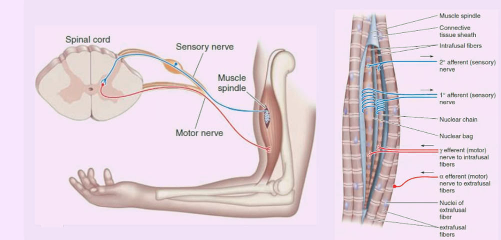
How does the brain integrate sensory inputs to execute movements?

How does expert behavior emerge?

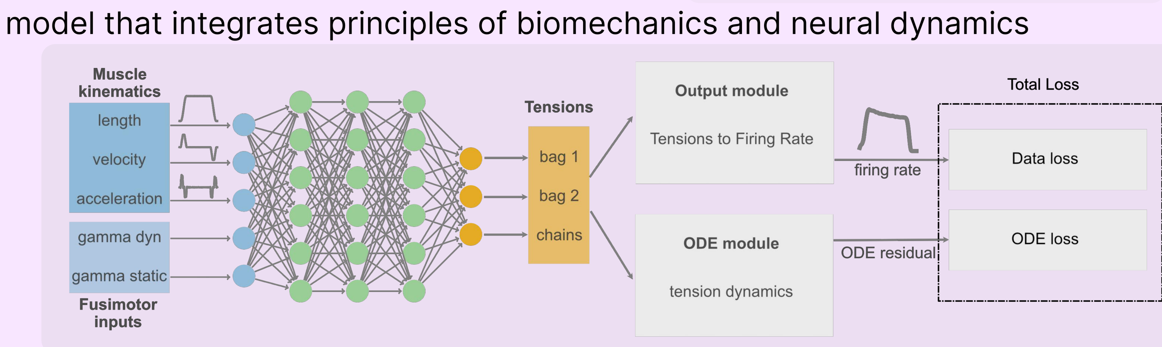


Modeling muscle spindles with Physics-Informed Neural Networks (PINNs)

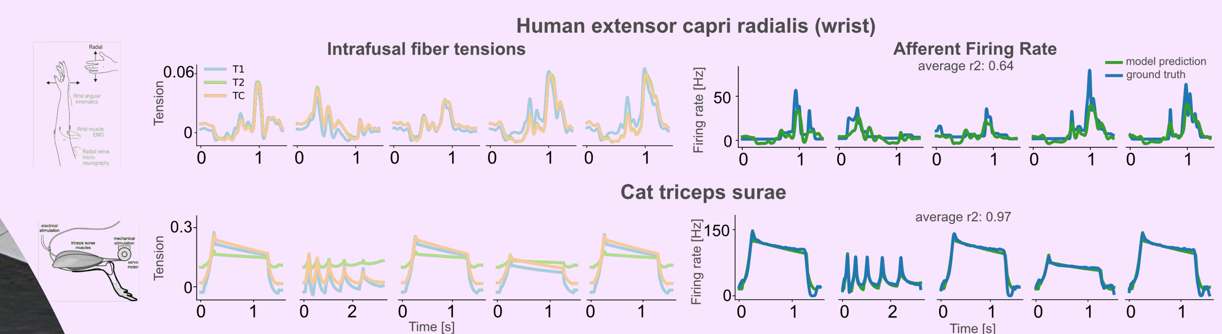
Muscle spindles convey information about the body position and movement to the central nervous system. By leveraging the power of PINNs we propose a model of muscle spindles that merges structural fidelity with computational efficiency.



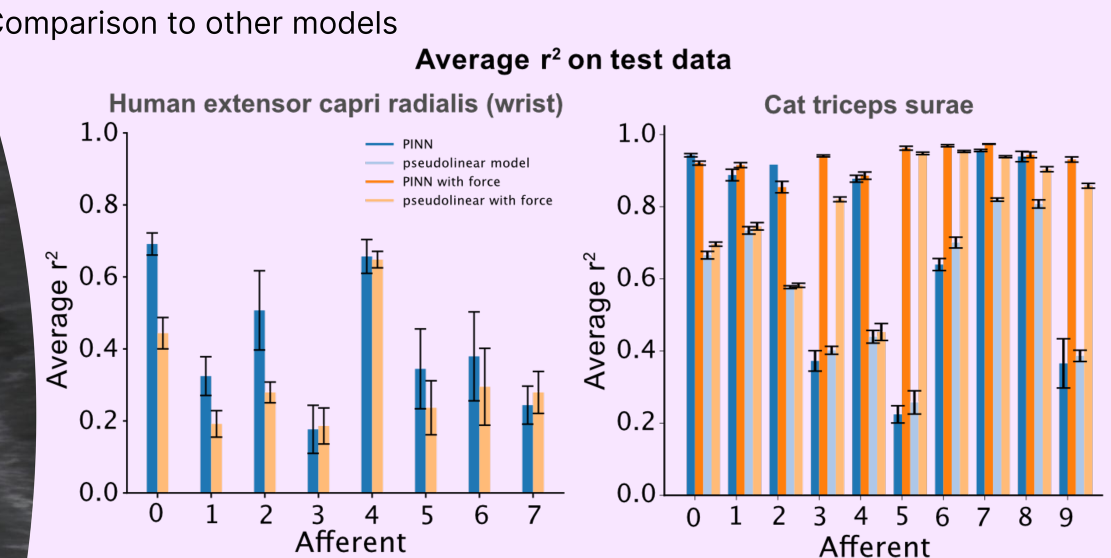
A model that integrates principles of biomechanics and neural dynamics



Validation on single trials from multiple datasets



Comparison to other models

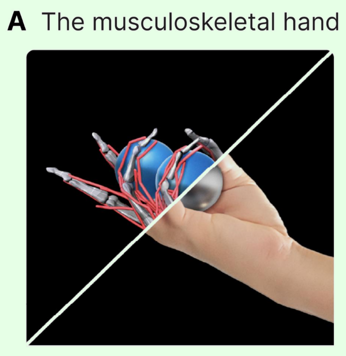


A. Perez Rotondo, M. Dimitriou, A., Mathis, A. "Modeling Sensorimotor Processing with Physics-Informed Neural Networks." (In preparation)

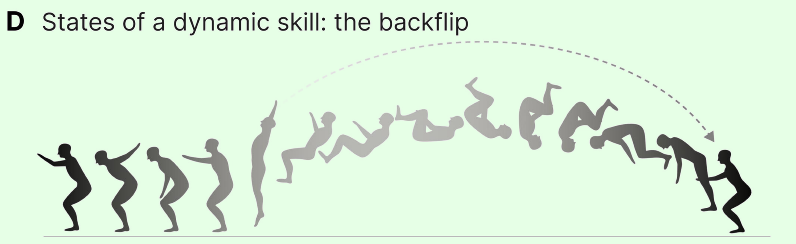
Acquiring musculoskeletal skills with curriculum-based reinforcement learning

Combining reinforcement and curriculum learning, we managed to win the NeurIPS MyoChallenge both in 2022 and 2023. Curriculum learning, similarly to coaching techniques used to train athletes, introduces progressively more complex task which facilitate the acquisition of sophisticated skills.

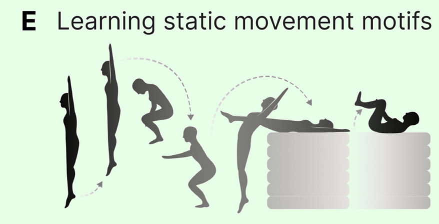
A The musculoskeletal hand



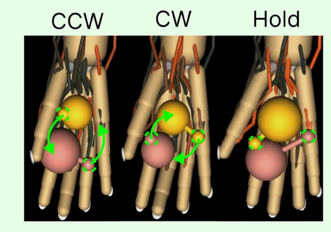
D States of a dynamic skill: the backflip



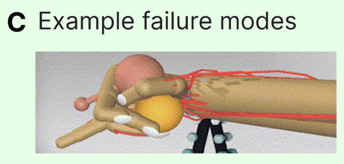
E Learning static movement motifs



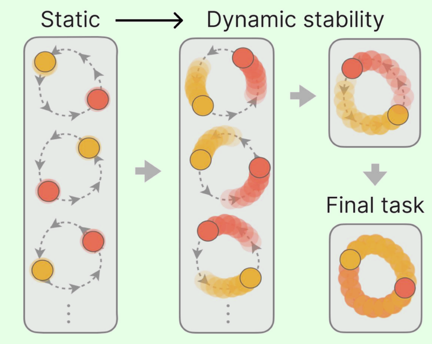
B Task variations



C Example failure modes



F Schematic of the SDS curriculum



G Ablation results

Curriculum	Performance	
	Phase 1	Phase 2
None	41%	0%
Location only	42%	4%
Speed only	45%	0%
SDS *(ours)*	**100%**	**55%**

H Challenge leaderboard

Rank	Performance	
	Phase 1	Phase 2
1 *(ours)*	**100%**	**55%**
2	98%	41%
3	48%	15%
4	62%	14%
5	12%	3%

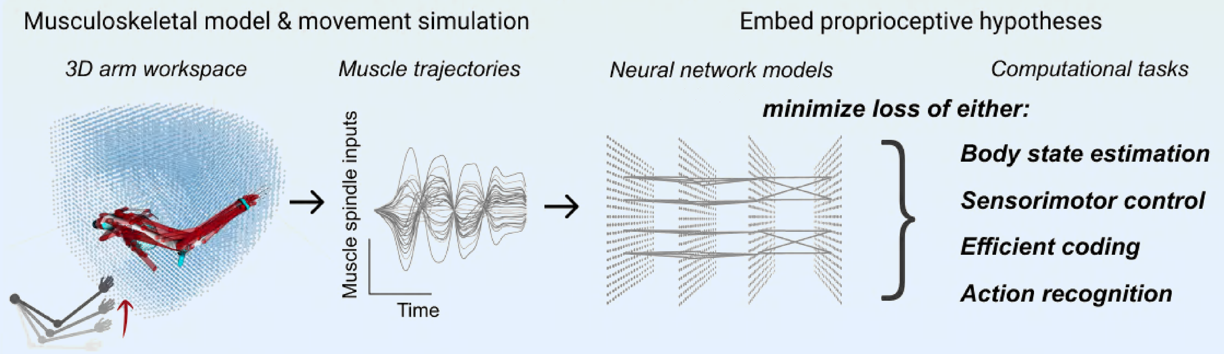
I

Chiappa*, A., Tano*, P., Patel*, N, Pouget, A., Mathis, A. "Acquiring musculoskeletal skills with curriculum-based reinforcement learning". BiorXiv, 2023.

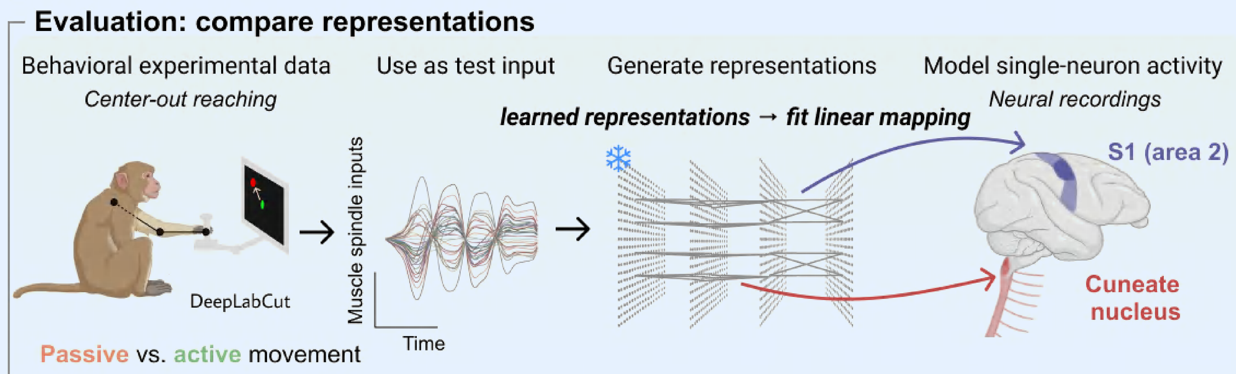
Modeling Proprioception with neural network models

We trained neural network models to solve proprioceptive computational tasks and we use the learned representation to predict neural activity to gain insights about how the brain perceives our body pose and movements.

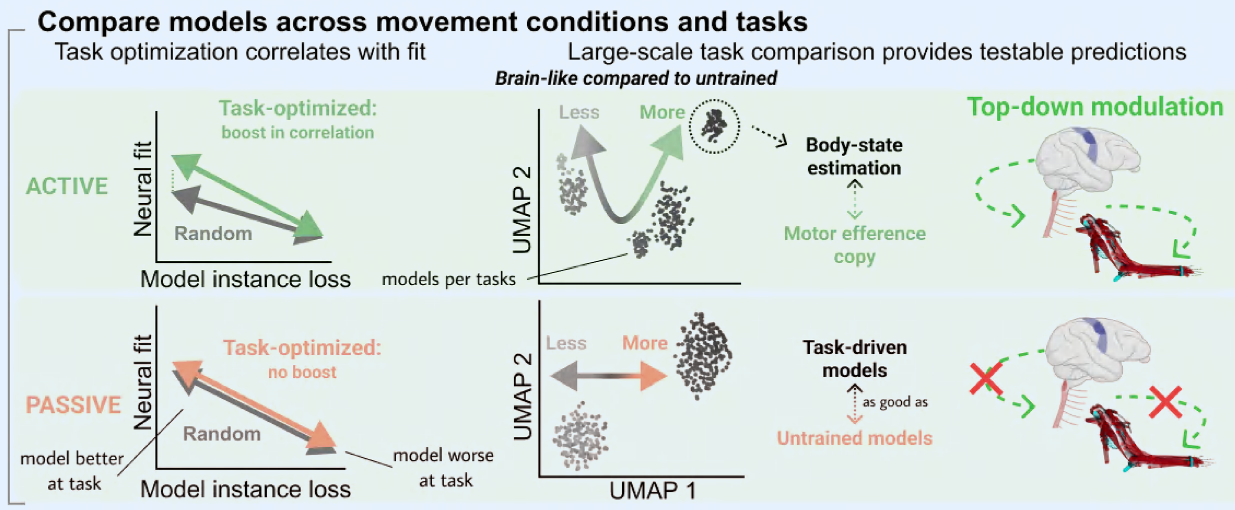
Hypothesis-driven framework to model proprioception



Evaluation: compare representations



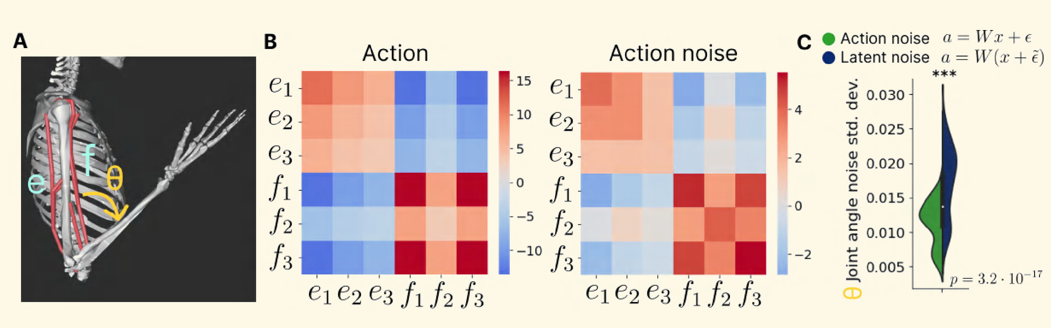
Compare models across movement conditions and tasks



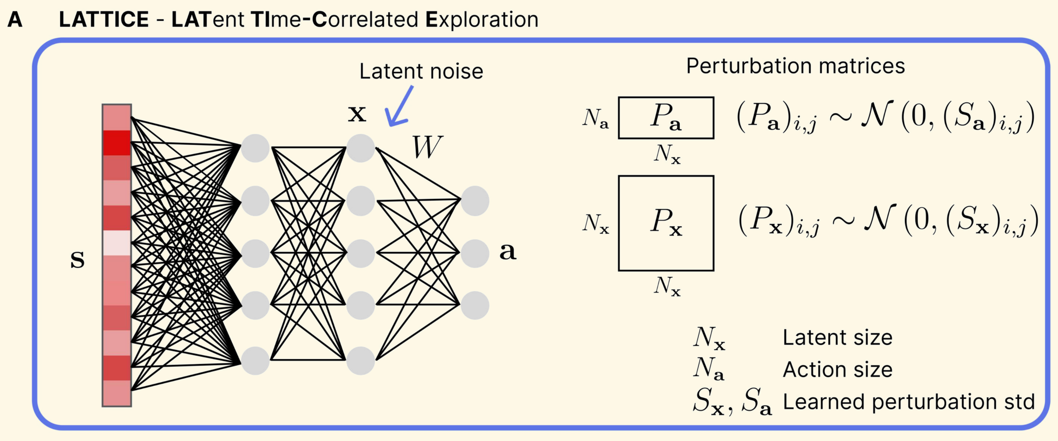
Marin Vargas*, A., Bisi*, A., Chiappa, A. S., Versteeg, C., Miller, L. E., & Mathis, A. "Task-driven neural network models predict neural dynamics of proprioception". Cell, 2024.

Latent exploration for reinforcement learning (Lattice)

Lattice is an exploration method which helps learning complex skills in complex environments through reinforcement learning. It uses the correlation across actuators learnt by the policy to give a structure to the exploration noise.



This is achieved by perturbing the latent state of the policy network.



Chiappa, A., Marin Vargas, A., Huang, A. Z., and Mathis, A. "Latent exploration for reinforcement learning". NeurIPS, 2023.

We used LATTICE to win the **2023 MyoChallenge**. Check out our solution!

We love open source!

Check out our website!

Selected collaborators:
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Michael Dimitriou, Umea University
Lee E. Miller, Northwestern University
Alexander Pouget, University of Geneva

Neuro X Institute

BRAIN MIND INSTITUTE

Swiss National Science Foundation