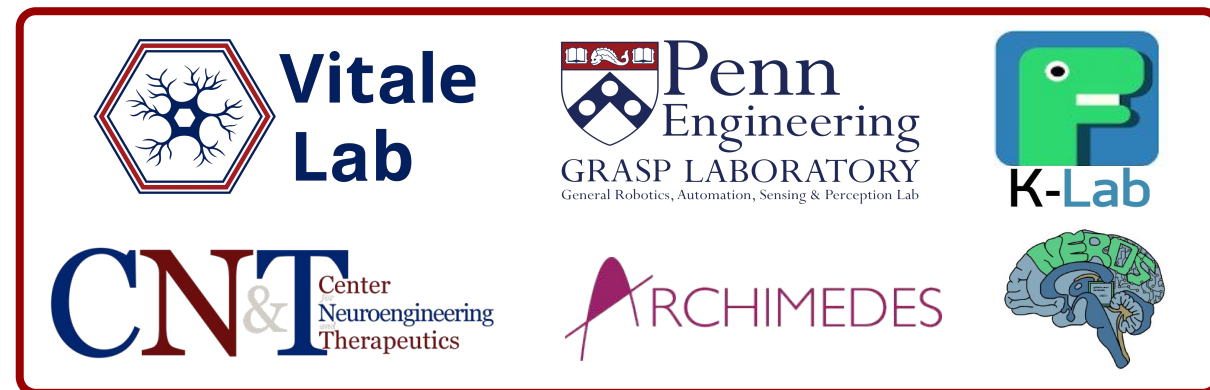
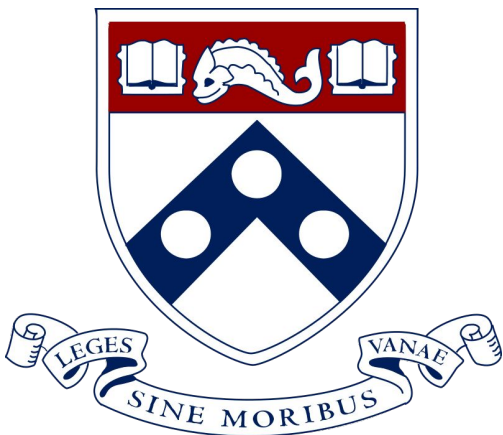




A Scalable, Causal, and Energy Efficient Framework for Neural Decoding with Spiking Neural Networks

39th Conference on Neural Information Processing Systems (NeurIPS 2025)



Georgios Mentzelopoulos^{1, *}, Ioannis Asmanis^{1, *}, Konrad P. Kording¹, Eva L. Dyer¹,
Kostas Daniilidis^{1, 2, †}, and Flavia Vitale^{1, †}

1. University of Pennsylvania, 2. Archimedes, Athena RC

^{*}, [†]Equal contribution; order determined by coin flip

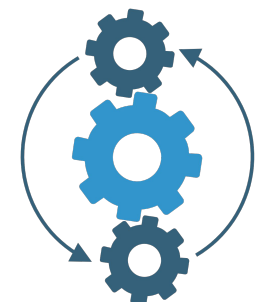
The burden of neurological disorders



**1 out of 3
people***



**Leading cause of disability
2nd leading cause of death**



**Need for technology that
can address incurable
neurological disorders**



**Amyotrophic
Lateral Sclerosis**



**Obsessive
Compulsive
Disorder**

Epilepsy

Depression



Multiple Sclerosis



Schizophrenia

**Attention Deficit
Disorder**

**Locked In
Syndrome**

Spinal Cord Injury



**Alzheimer's
Disease**



**Parkinson's
Disease**

Tremor

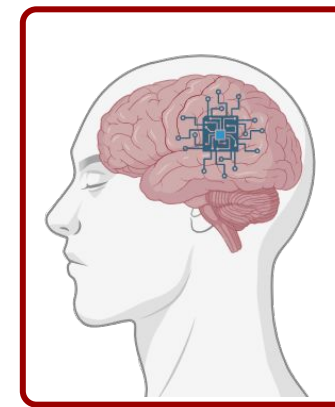
*V.L. Feigin, et. al. Lancet (2019)

The promise of brain-computer interfaces



Singer-Clark T., et. al. J Neural Eng (2025)

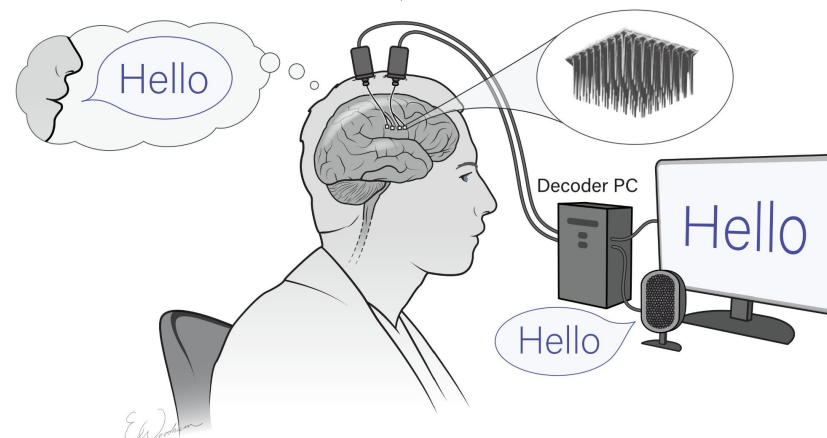
Brain-Computer Interfaces (BCIs)



Strong neural decoders can introduce revolutionary therapeutics



Hochberg, L. R., et al. Nature (2012)



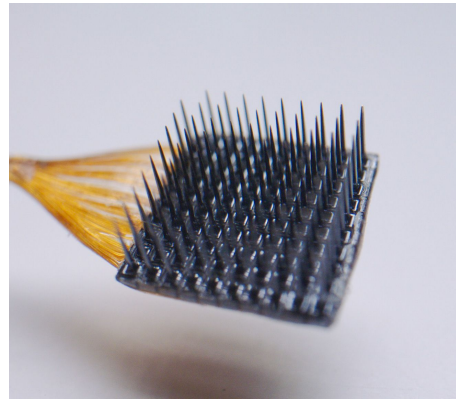
Willet R.F., et. al. Nature (2023)



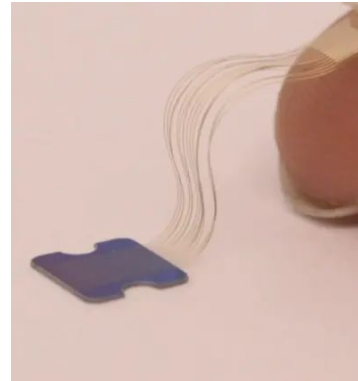
Neuralink (2024)

Complex tasks require complex information

Number of recording electrodes keeps increasing



Utah Array
96 channels

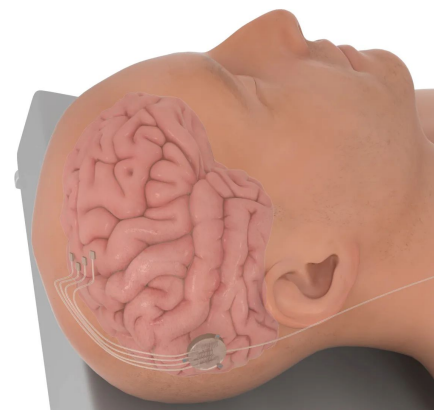
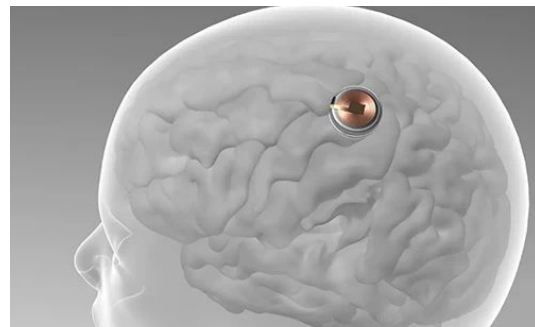


N1 (Neuralink)
1024 channels



Connexus (Paradromics)
1684 channels

Device size keeps decreasing



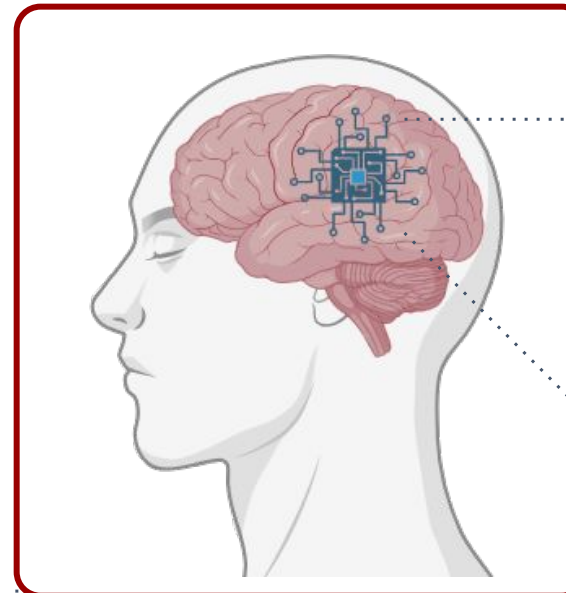
Computational demands increase

Need: Energy efficient computation

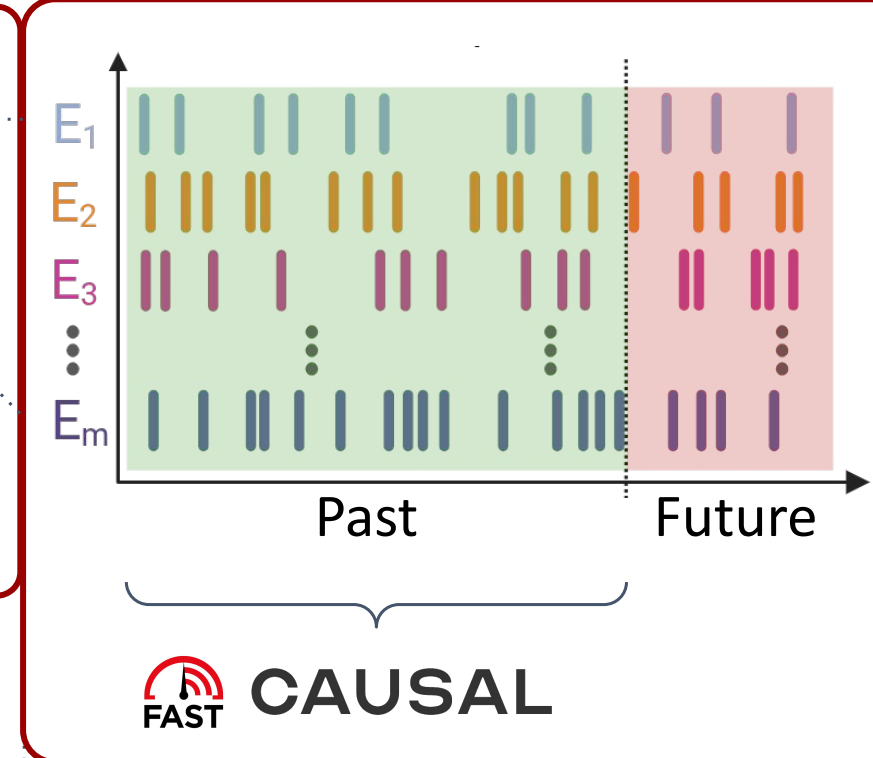
Available battery decreases

The landscape of current models

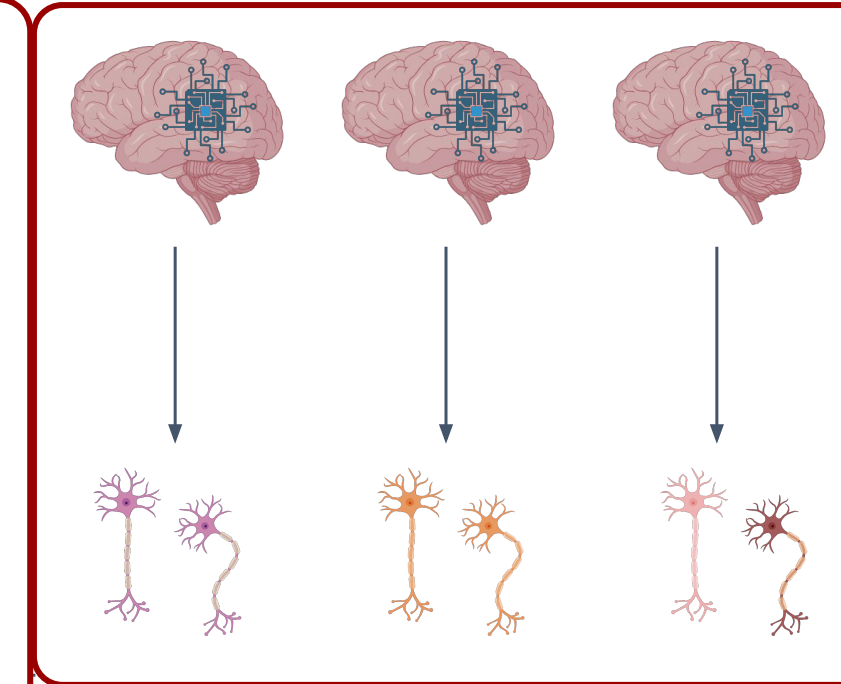
Energy efficiency



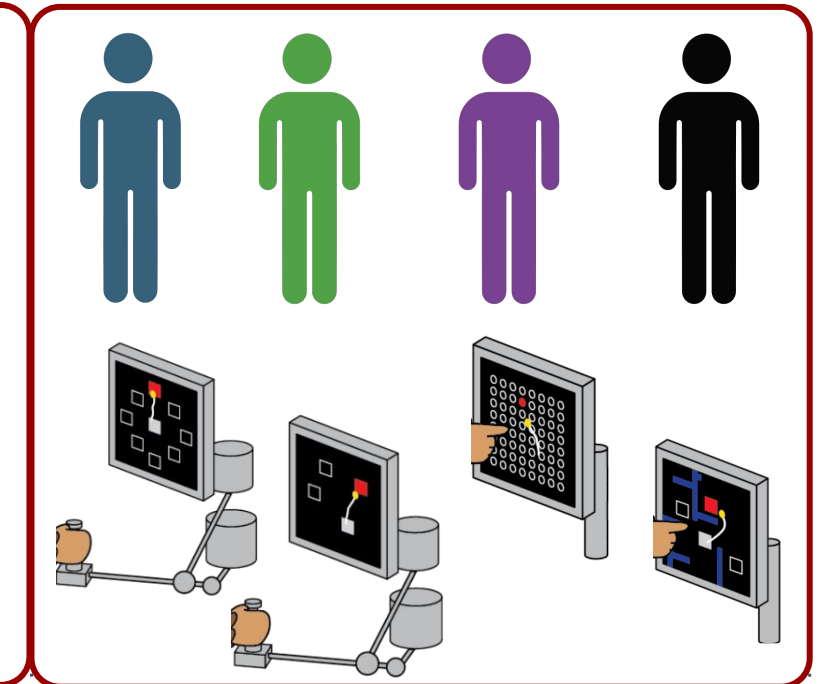
Online usability



Scalability



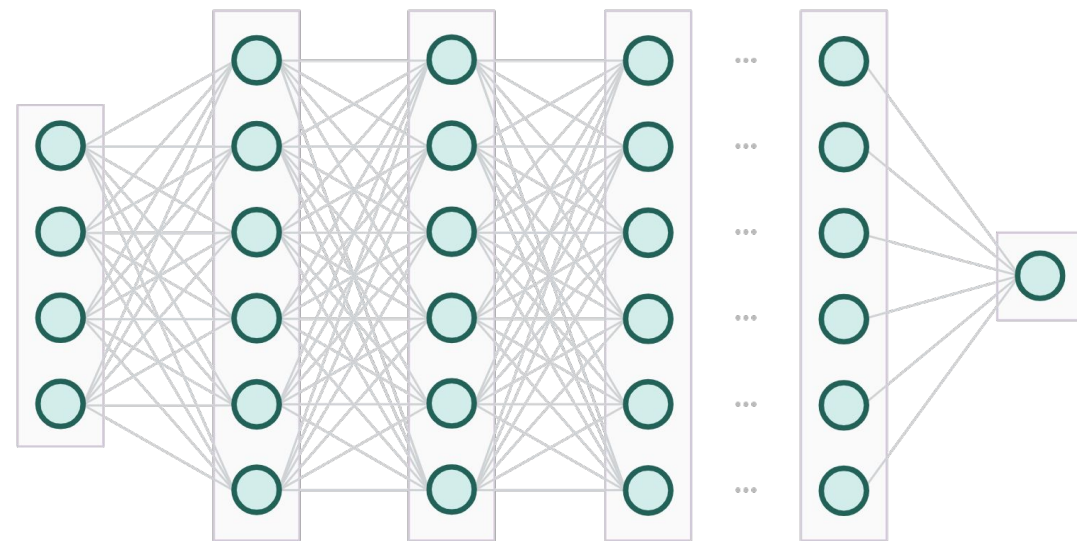
Generalization



Models	Energy efficiency	Online usability	Scalability	Generalization
Wiener Filt., MLPs, RNNs...	—	+	—	—
LFADS, POYO(+), CEBRA...	—	—	+	+

Computational alternative to artificial neural networks

Artificial Neural Networks (ANNs)

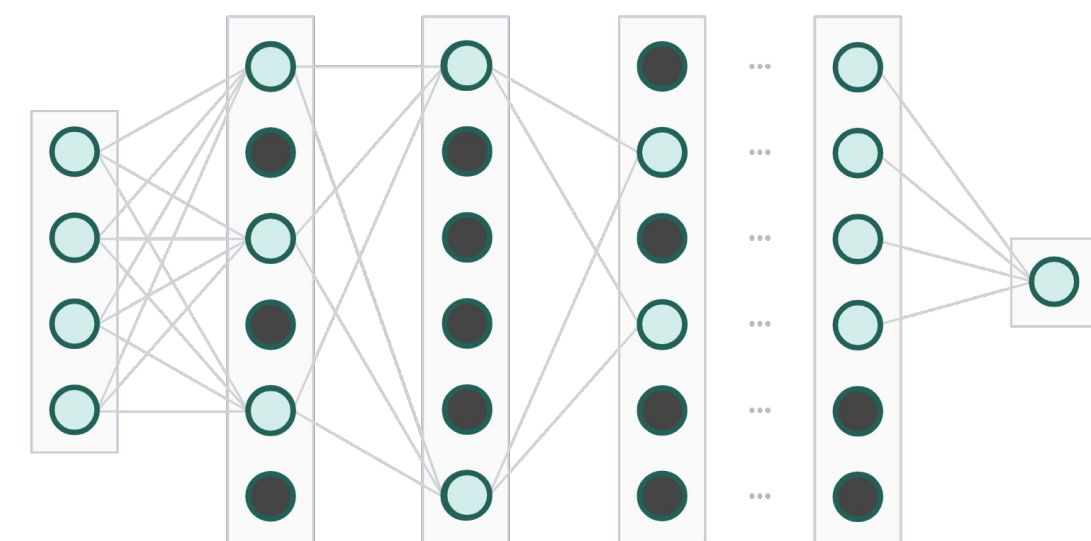


All neurons are active

Energy Consumption: 🔥 🔥 🔥



Spiking Neural Networks (SNNs)



Small subset of neurons active

Energy Consumption: 🔥

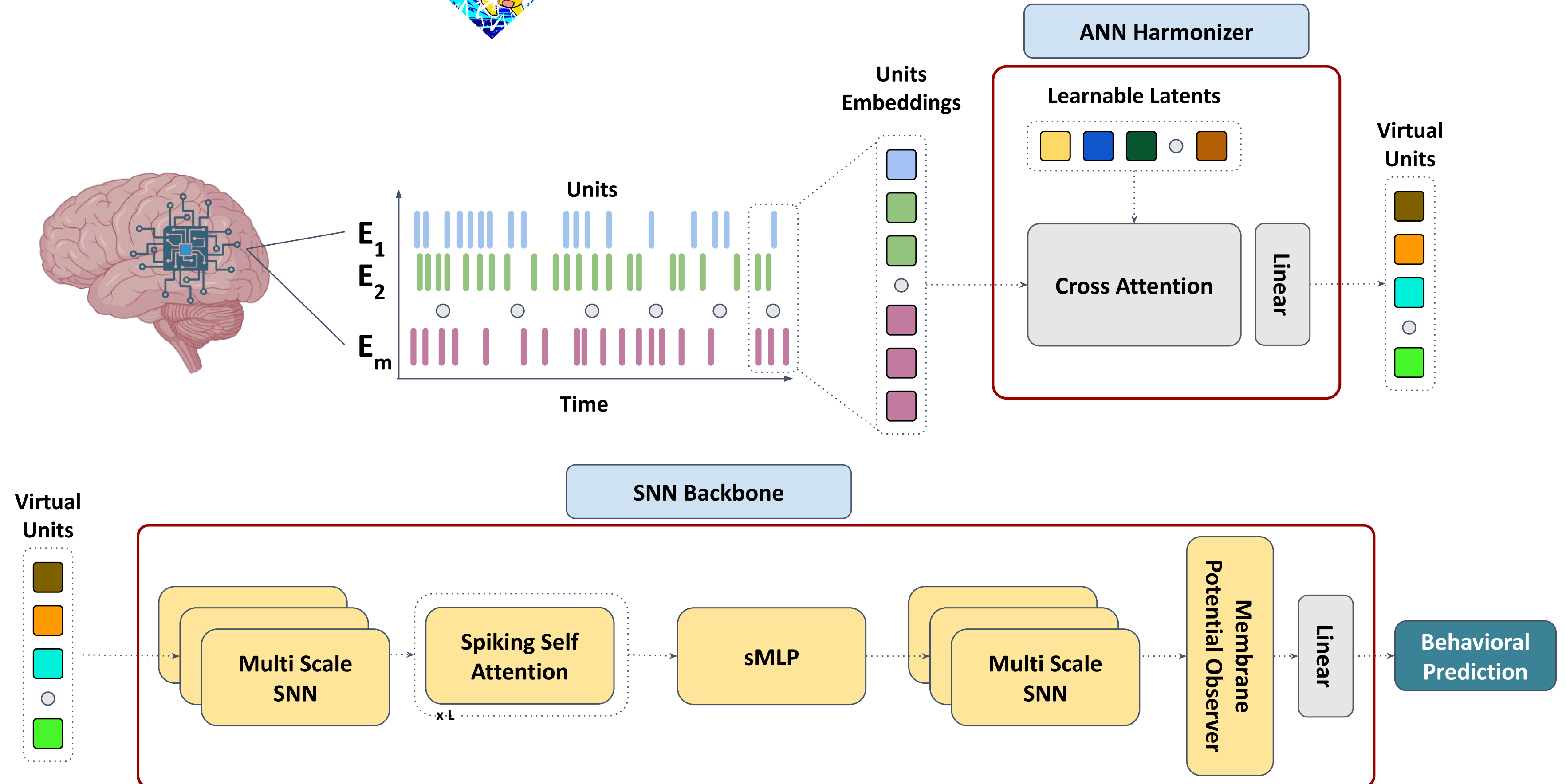


Can we build effective neural decoders using Spiking Neural Networks?

Framework: Spikachu

- I. Harmonization based on ANNs
- II. Bulk Processing based on SNNs

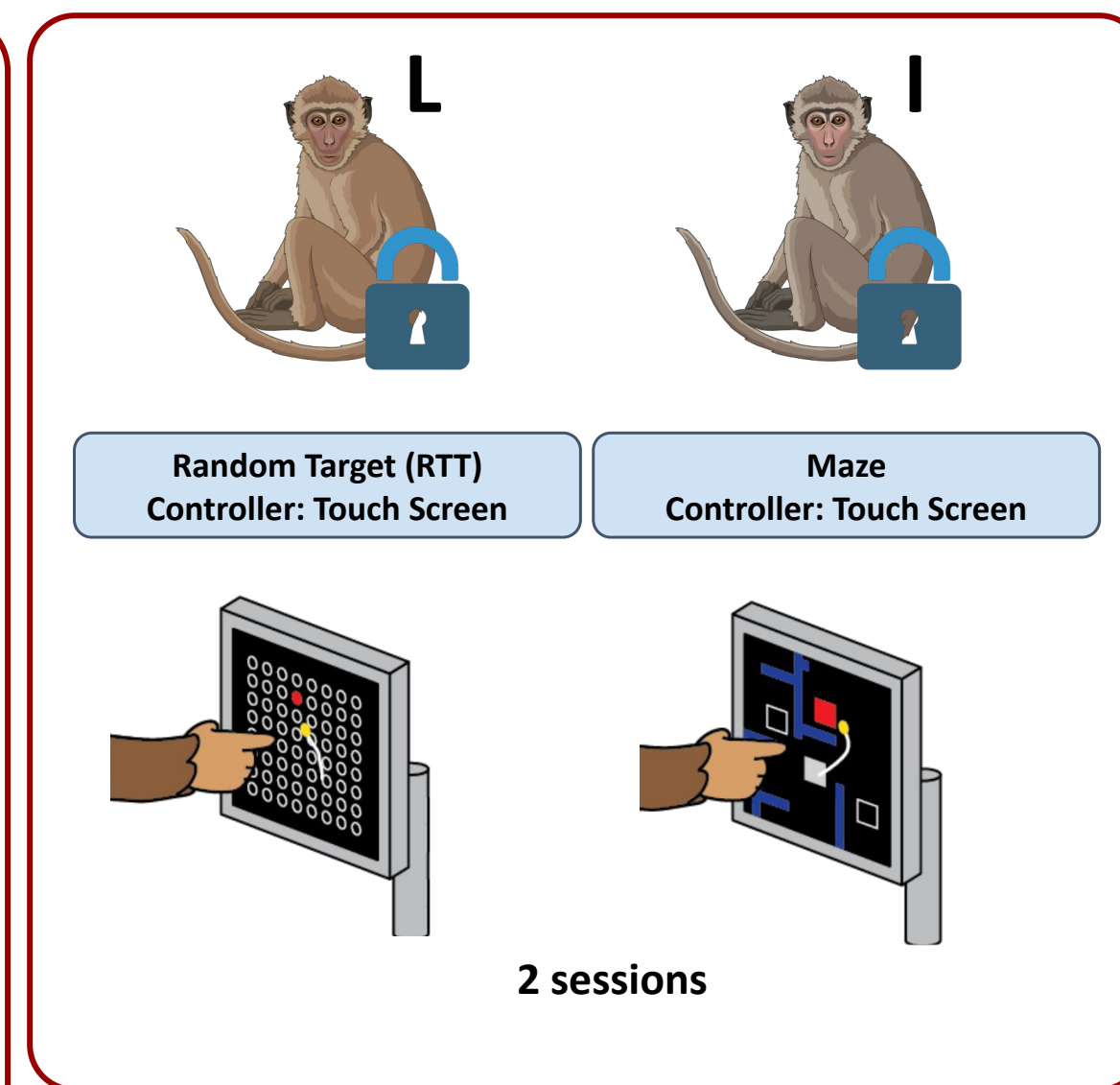
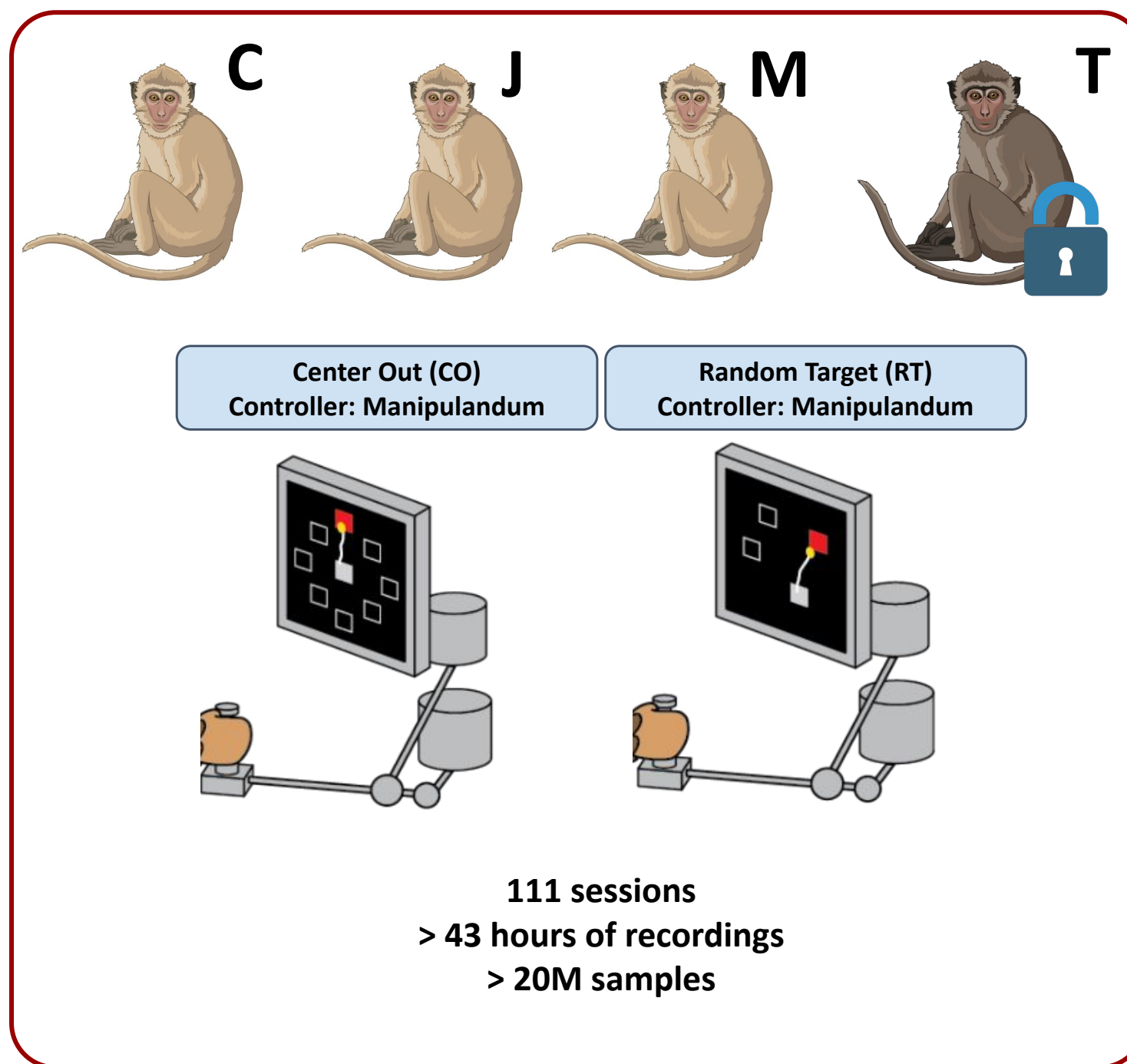
Framework: Spikachu



Experiments

- I. Dataset
- II. Single-session models + baselines
- III. Multi-session, multi-subject models
- IV. Transferring to new subjects
- V. Scaling laws of multi-session training
- VI. Transferring to new subjects + new tasks

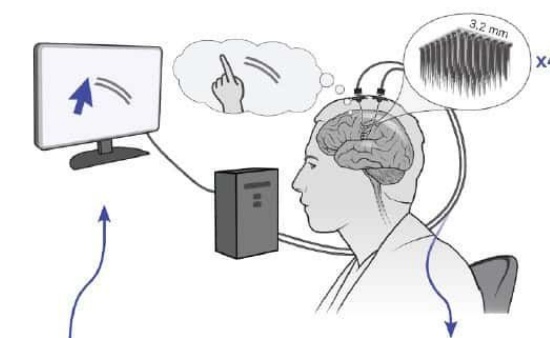
Dataset* used to evaluate our approach



Held Out for
testing

*Curated by Azabou M., et. al. NeurIPS (2023)

Goal: Decode cursor velocity from the monkey's neural data



Single-session models + baselines

Single-session



Spikachu

R^2 : 0.84

E : 5.14 μ J

R^2 : 0.68

E : 5.13 μ J

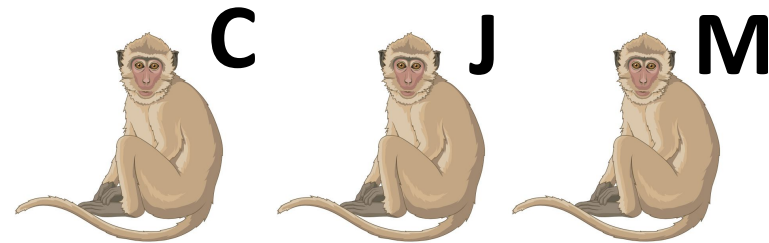
Performance Evaluation

Decoding Accuracy

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y}_i)^2}$$

Energy Efficiency[‡]

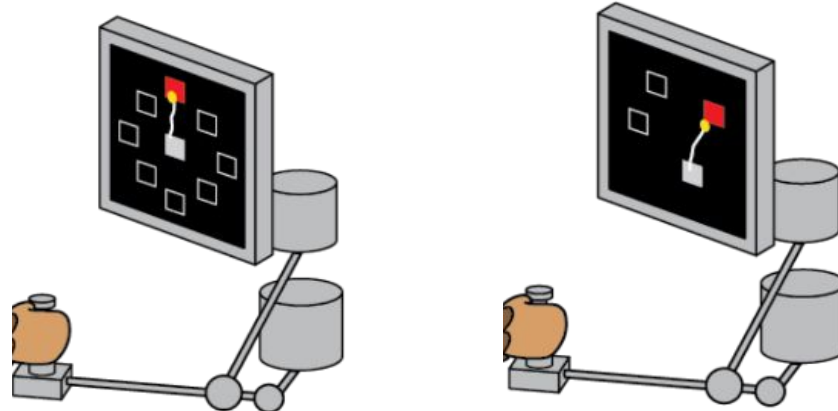
$E \sim \text{FLOPs}$



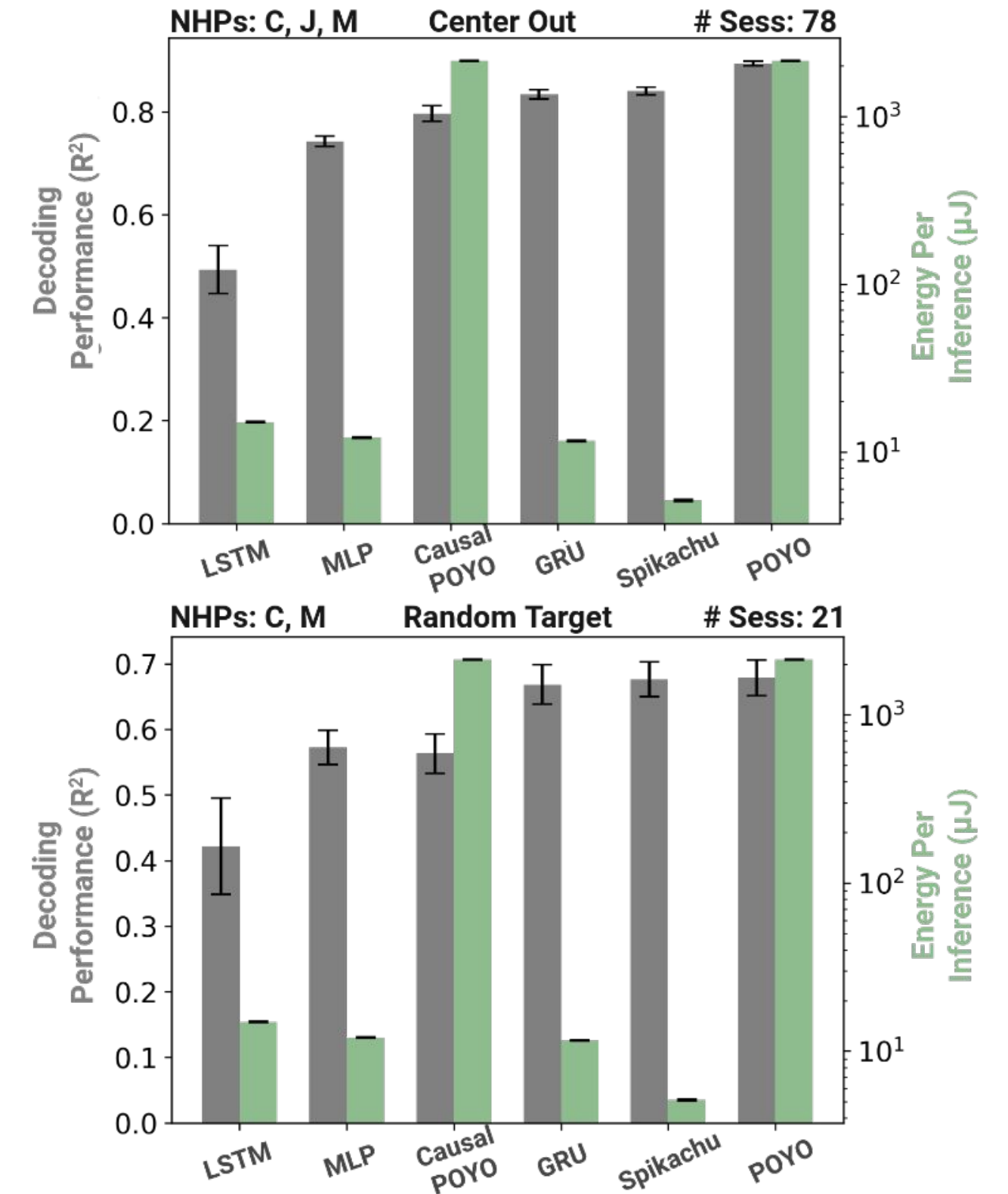
99 sessions

Center Out (CO)
Controller: Manipulandum

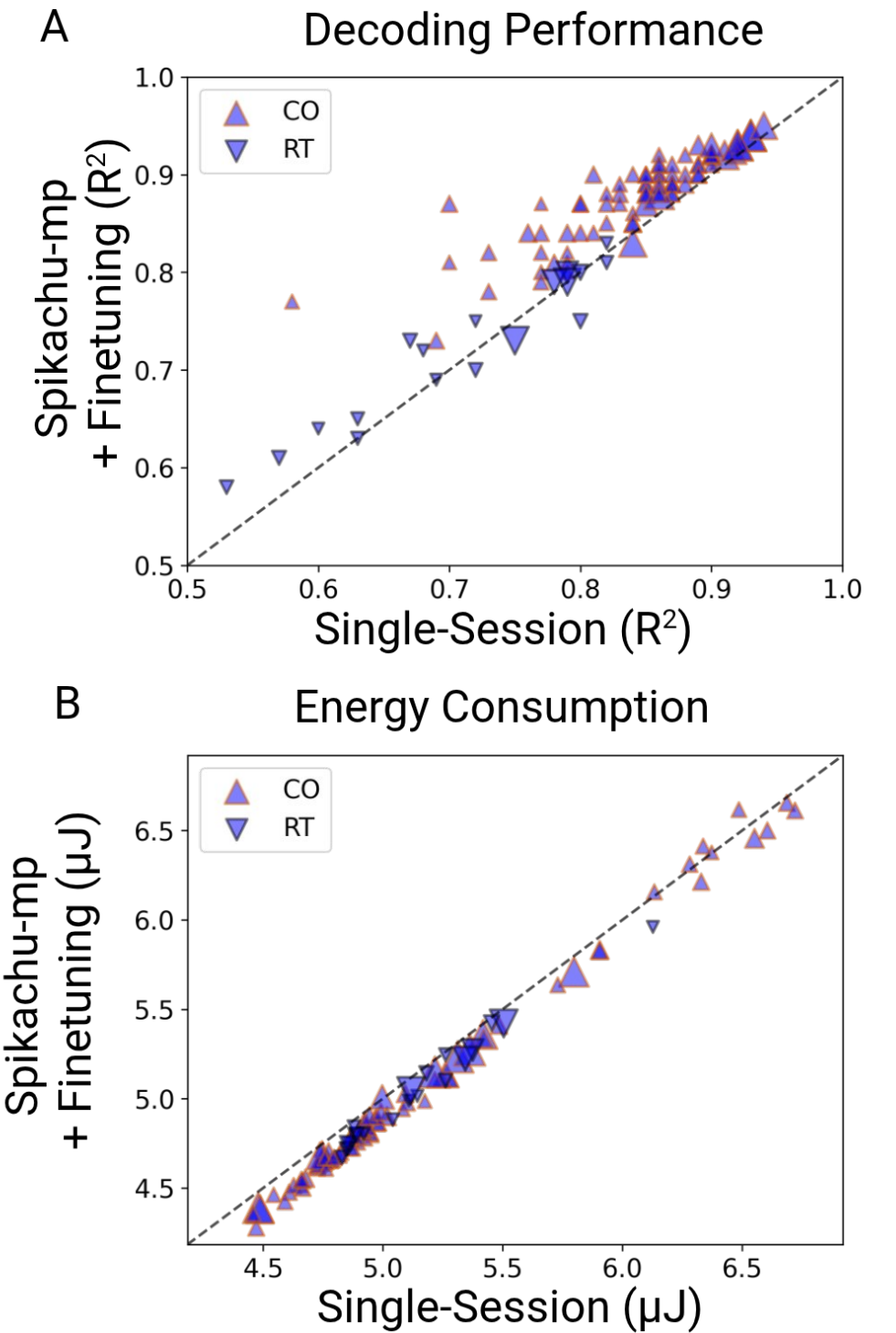
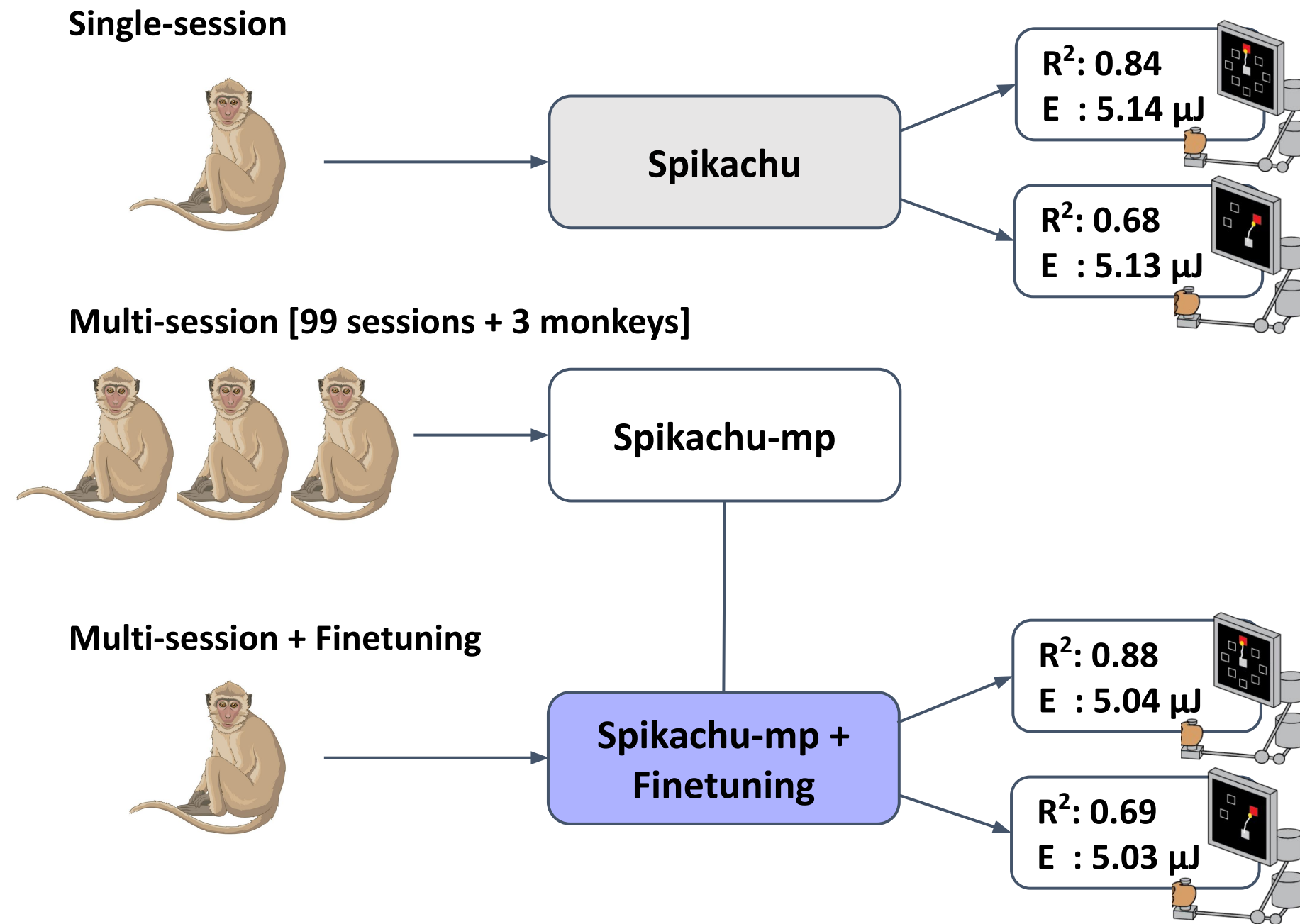
Random Target (RT)
Controller: Manipulandum



Baseline Comparisons



Multi-session, multi-subject models

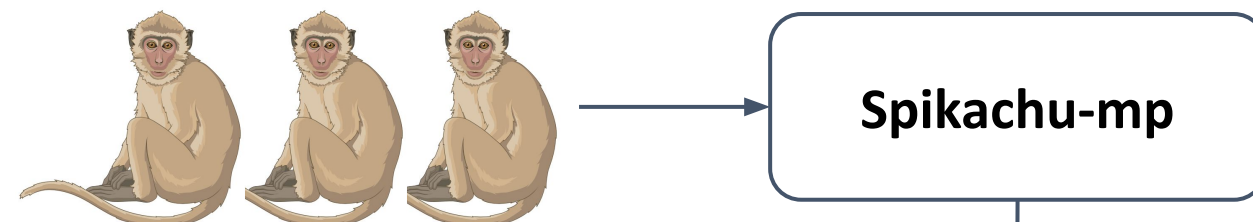


Transferring to new subjects

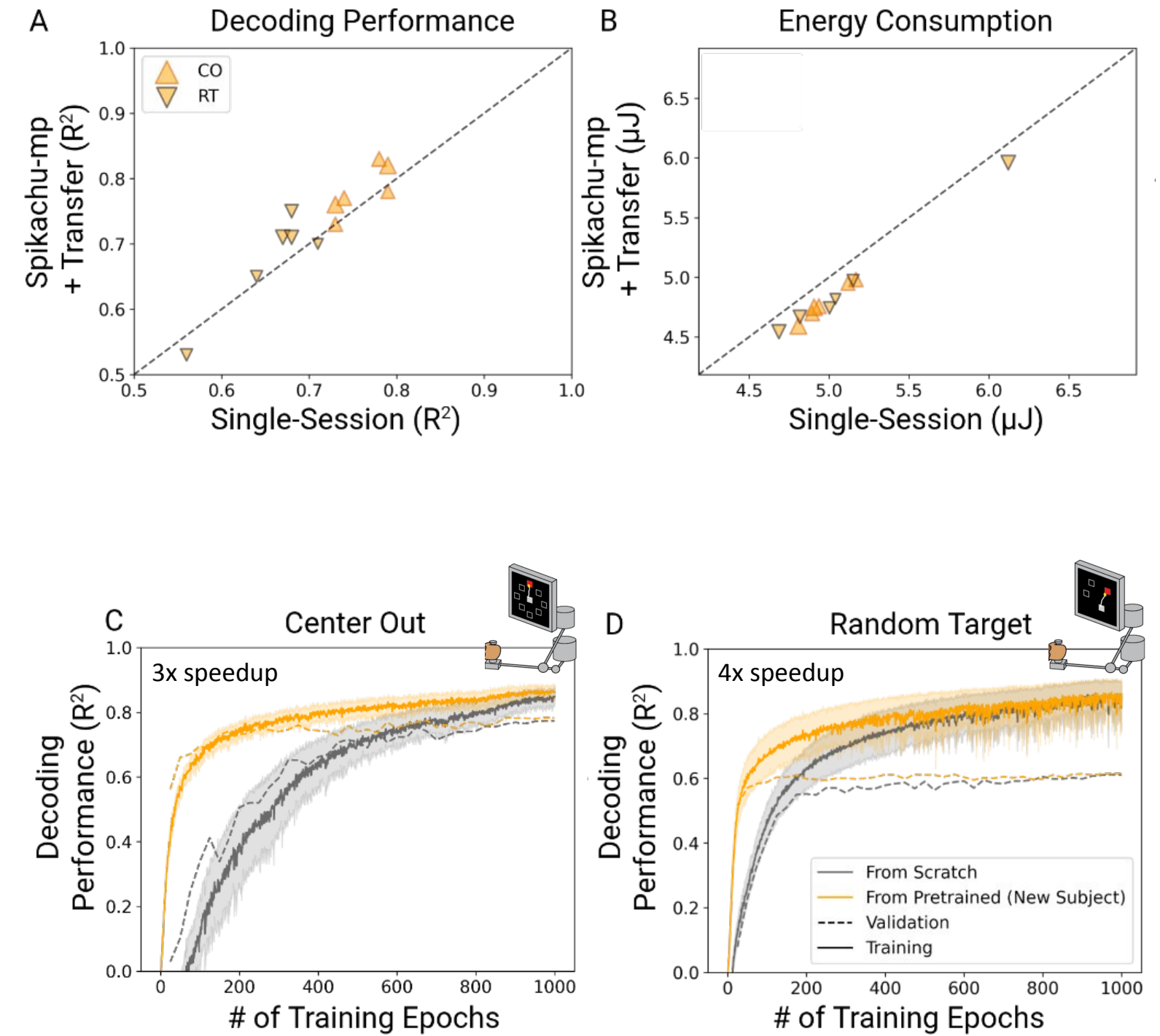
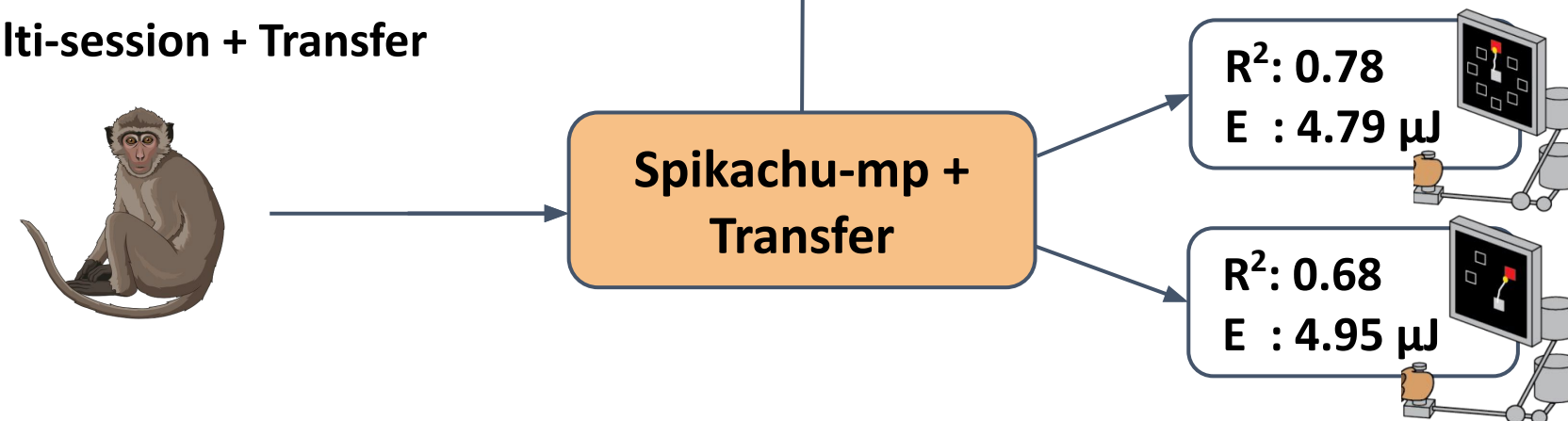
Single-session



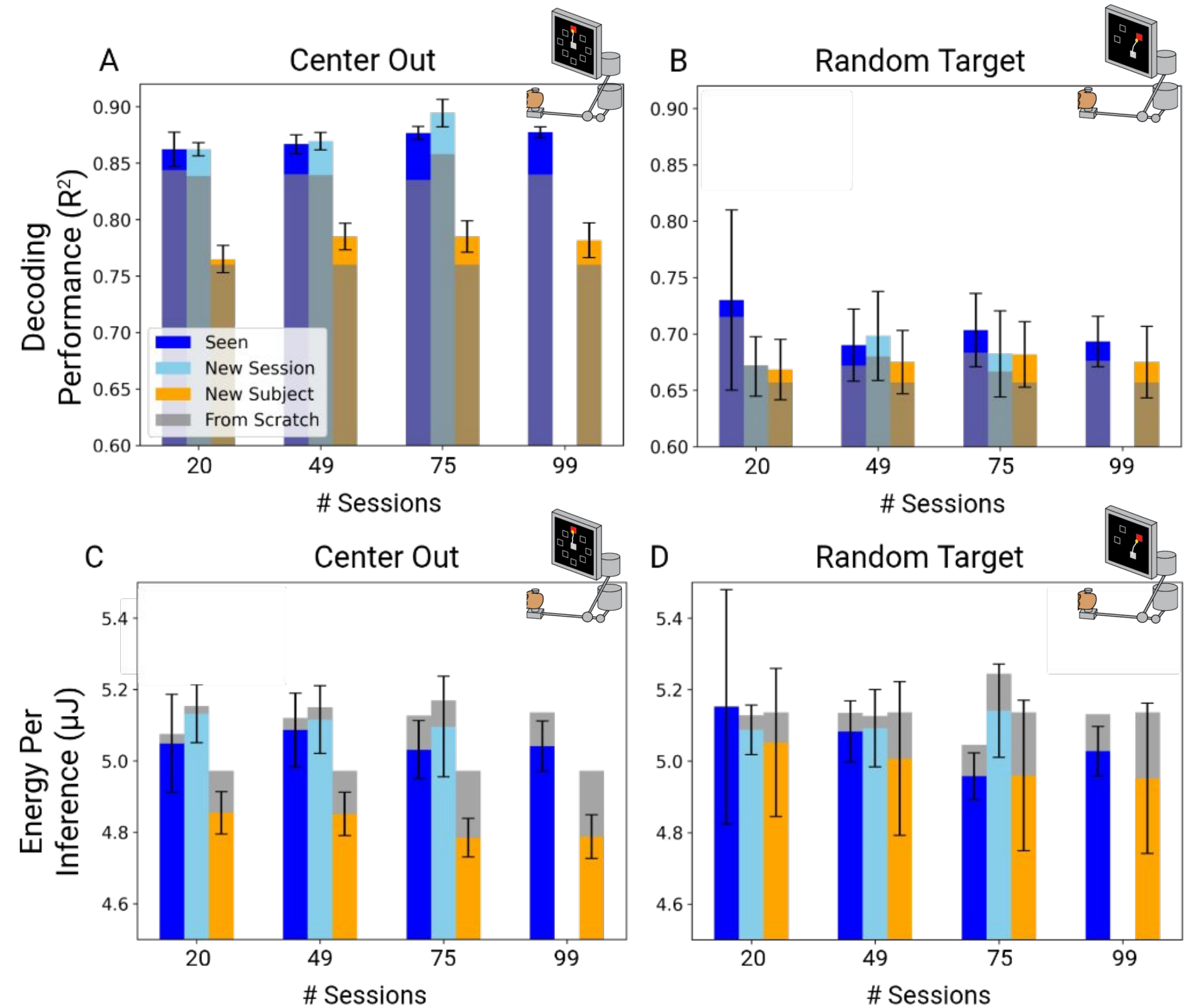
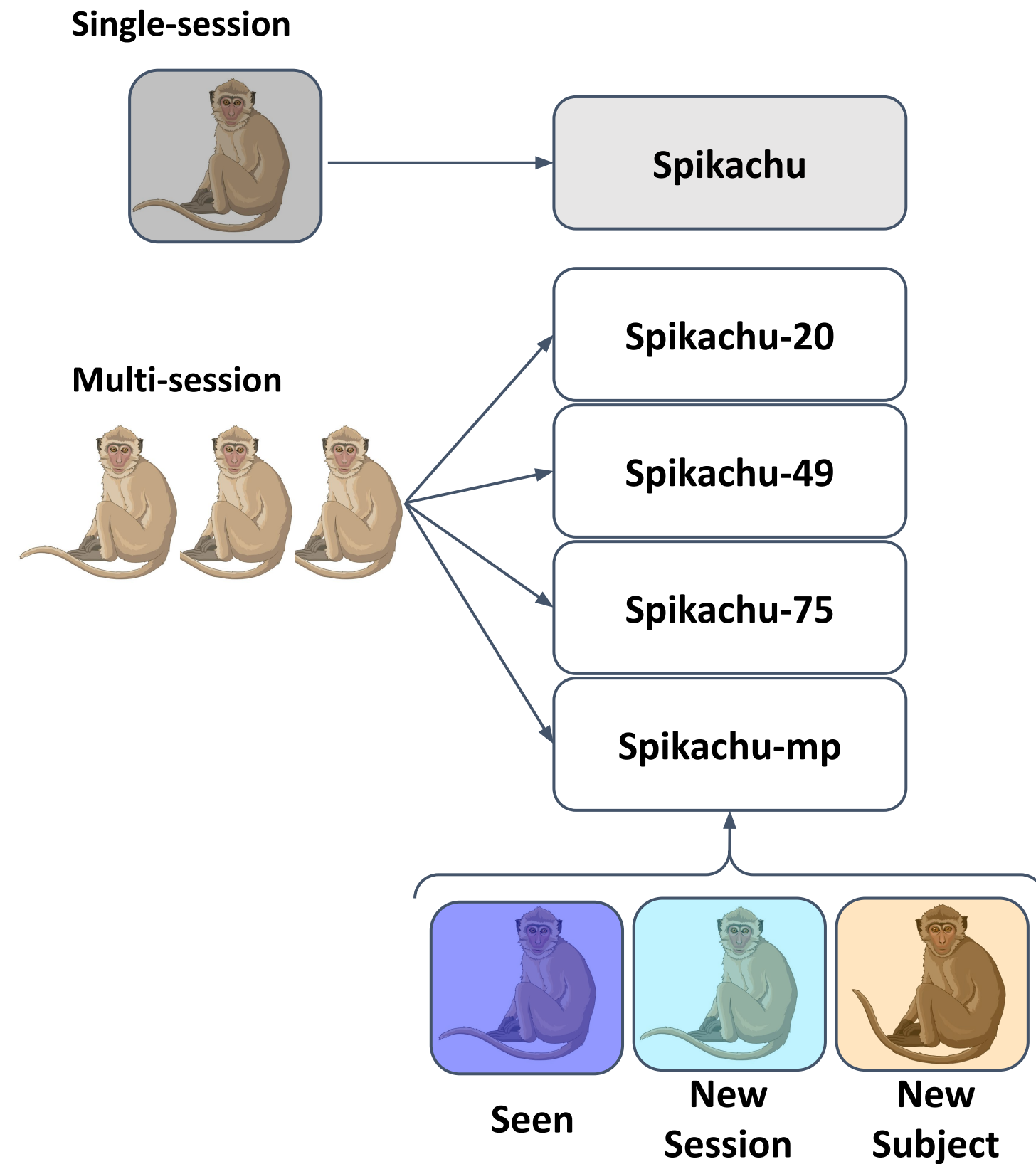
Multi-session [99 sessions + 3 monkeys]



Multi-session + Transfer

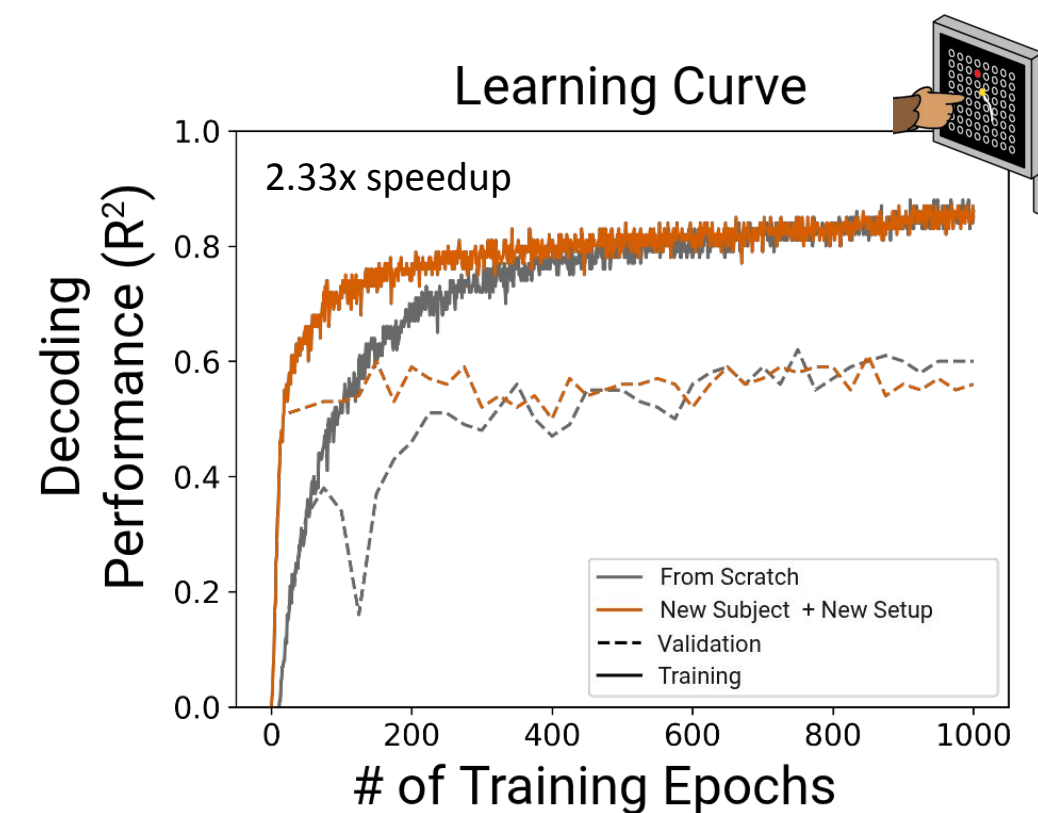
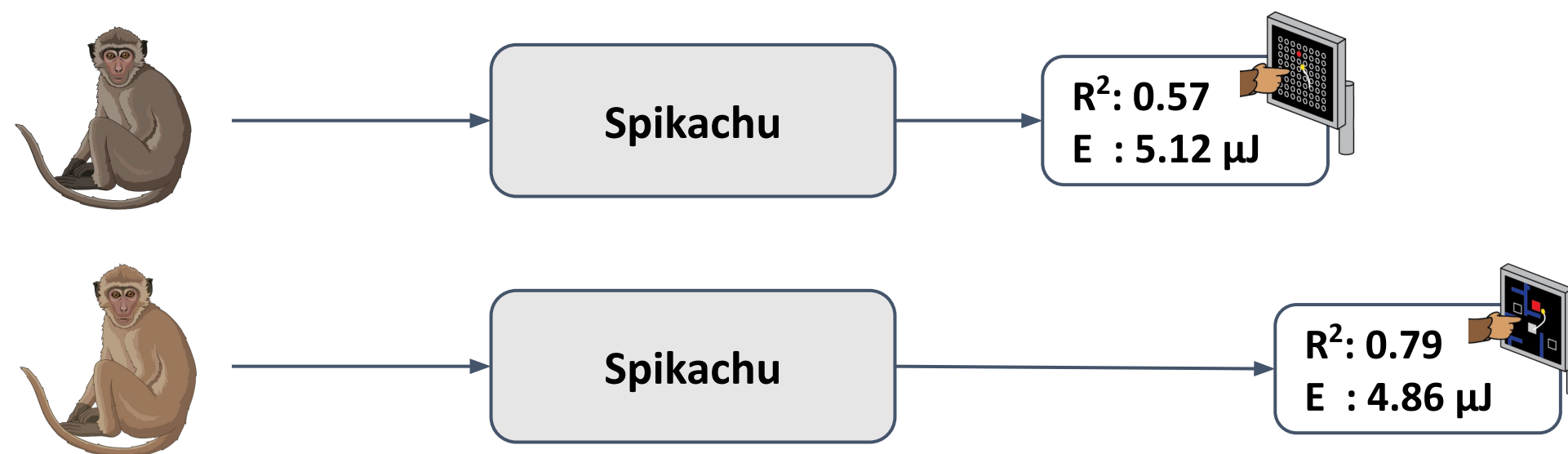


Scaling laws of multi-session training

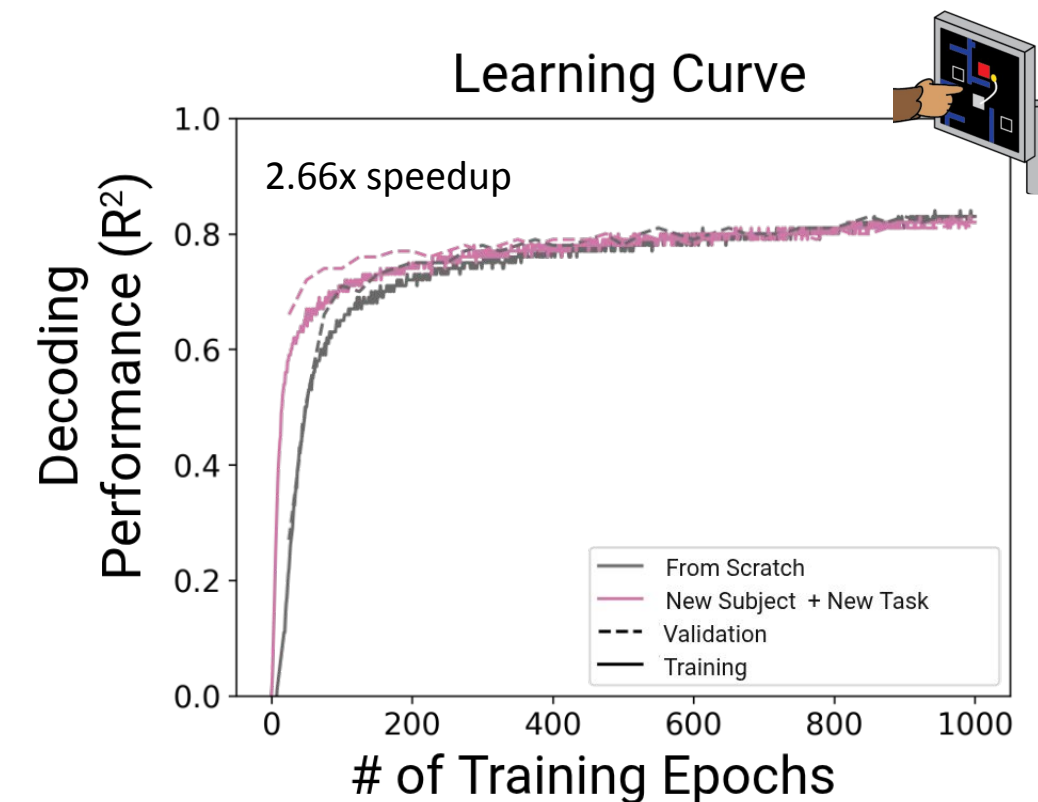
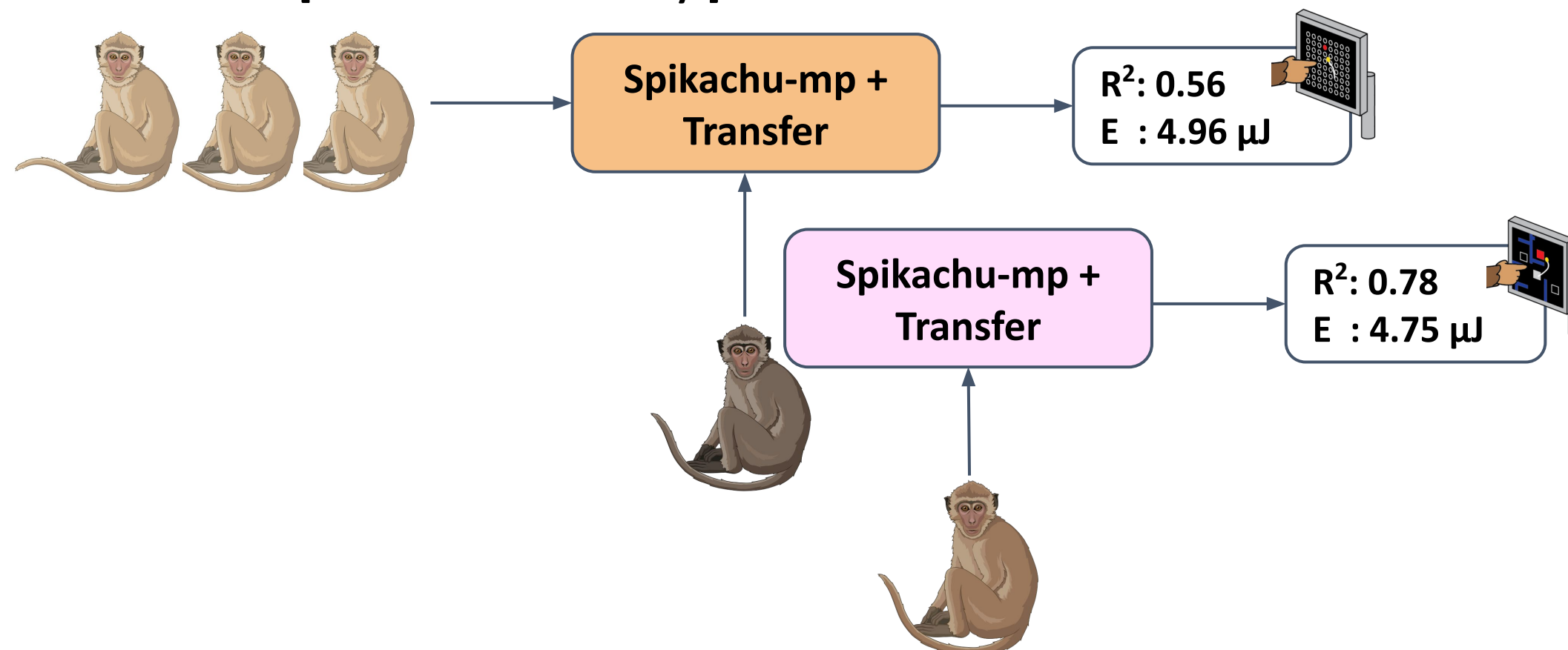


Transferring to new subjects + new tasks

Single-session

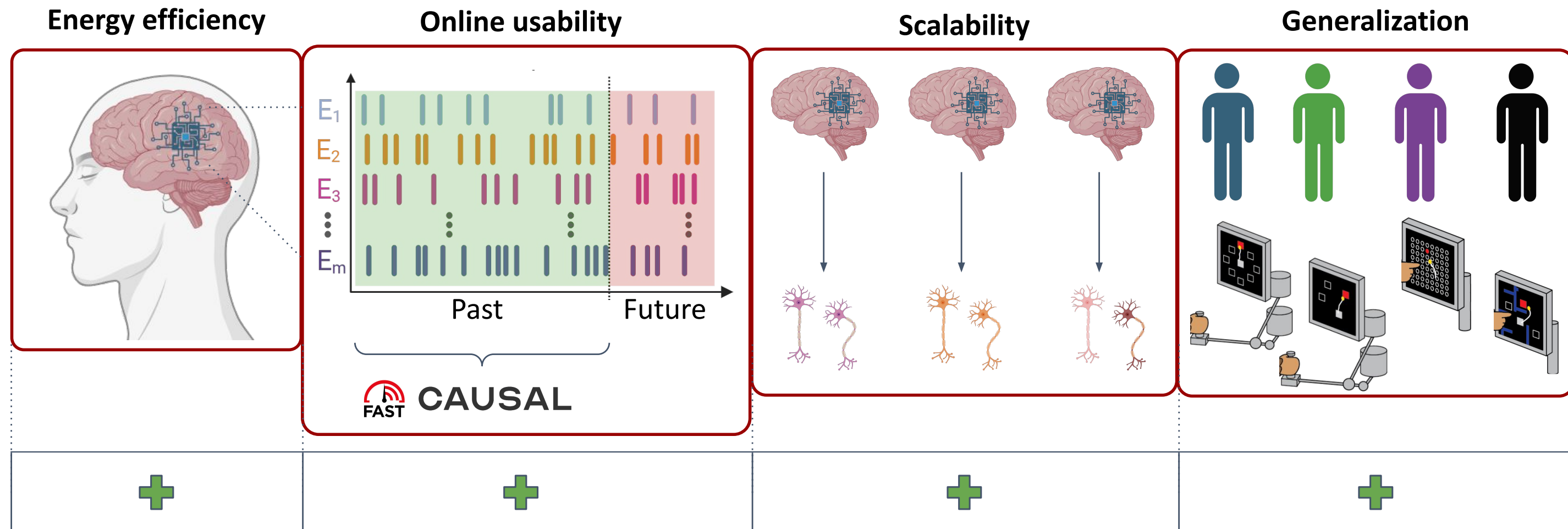


Multi-session [99 sessions + 3 monkeys]



Summary

- We introduce Spikachu: a causal, scalable, and energy-efficient framework for neural decoding.
- Importance: Our work paves the way towards BCIs that perform all around while consuming minimal energy.



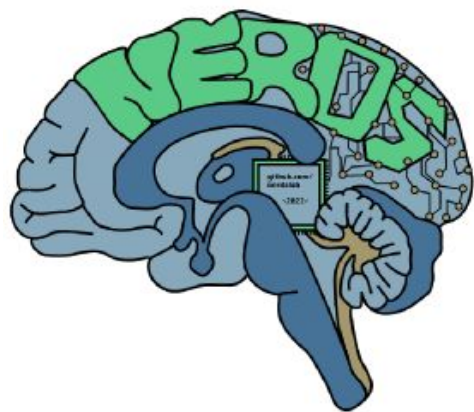
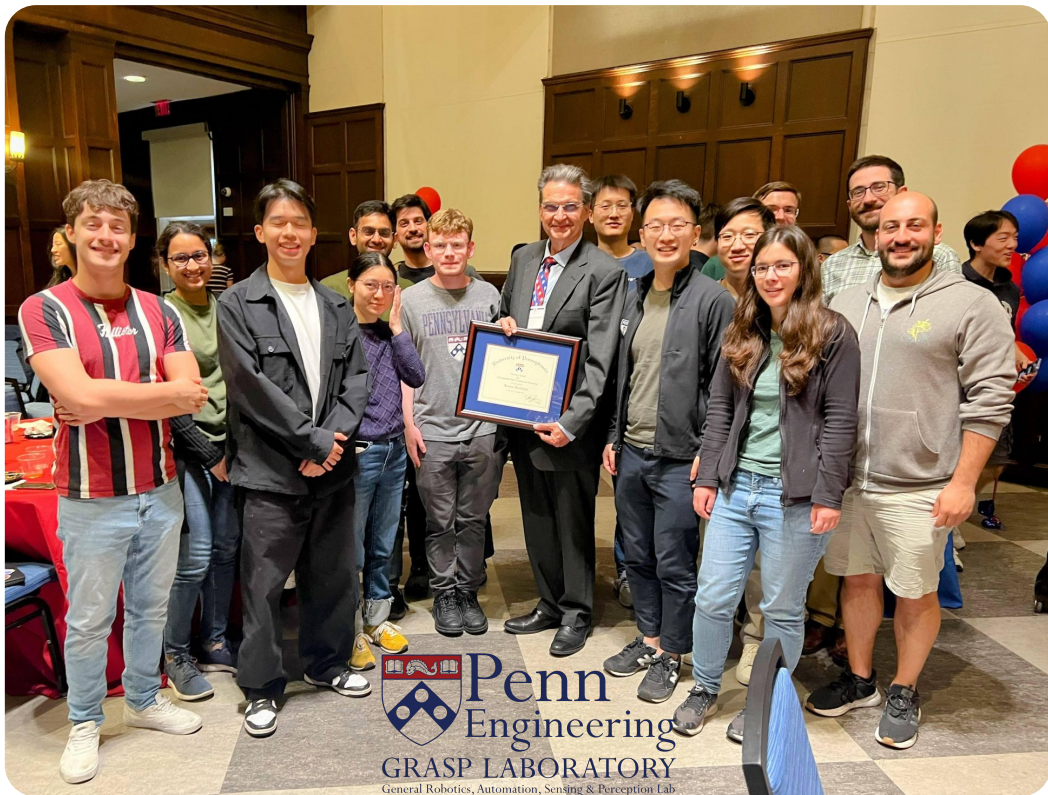
Our paper and code is available at
<https://spikachu-bci.github.io/>



Acknowledgements



Team Spikachu



**BODOSSAKI
FOUNDATION**

**ONASSIS
FOUNDATION**

