

Efficient Neuromorphic Braille Discrimination in a Predictive-Coding-Inspired Spiking Network

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Motivation

Braille

- Recognize spatial patterns through spatiotemporal integration.
- Requires working memory
- Intrinsic sensory variability and noise.

Current approaches

Often rely on supervision and backpropagation through time [Müller-Cleve et al. 2022].

Our objective

Learn a robust tactile-memory representation for Braille reading through unsupervised local plasticity rules.

Main Findings

Emergence

Receptive fields self-organize from unstructured connectivity.

Sparsity coding

Neural competition through inhibitory synaptic plasticity leads to sparse representations.

Generalization

Unseen patterns are represented from learned column primitives.

Robustness

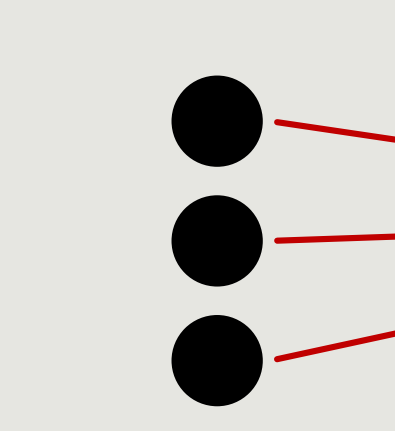
Representations remain separated under $\pm 50\%$ pressure variation.

Memory

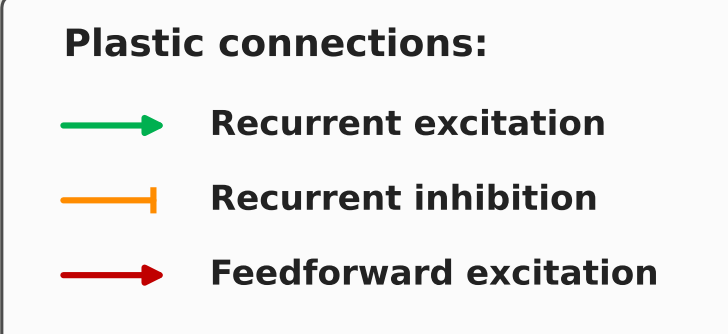
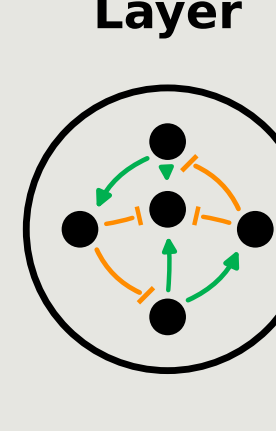
Recurrent dynamics generate and maintain sequence-specific trajectories.

CMOS-Compatible Predictive-Coding-Inspired Architecture

Input Layer



Encoding Layer



Layer 1

Input

SA-like tactile encoding.

Neurons

CADEx with recurrent E/I connectivity [Livi et al. 2009].

Plasticity

Local Ca-STDP [Girão et al. 2025].

Computation

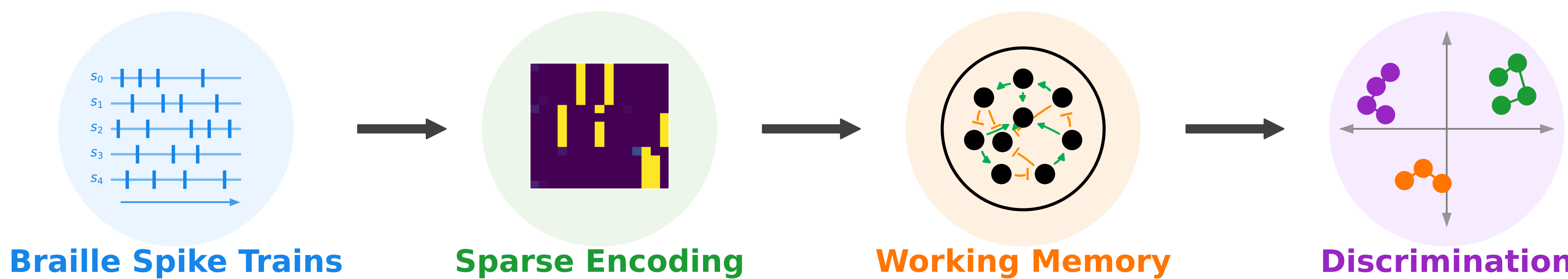
Prediction-error-inspired competition.

Hardware

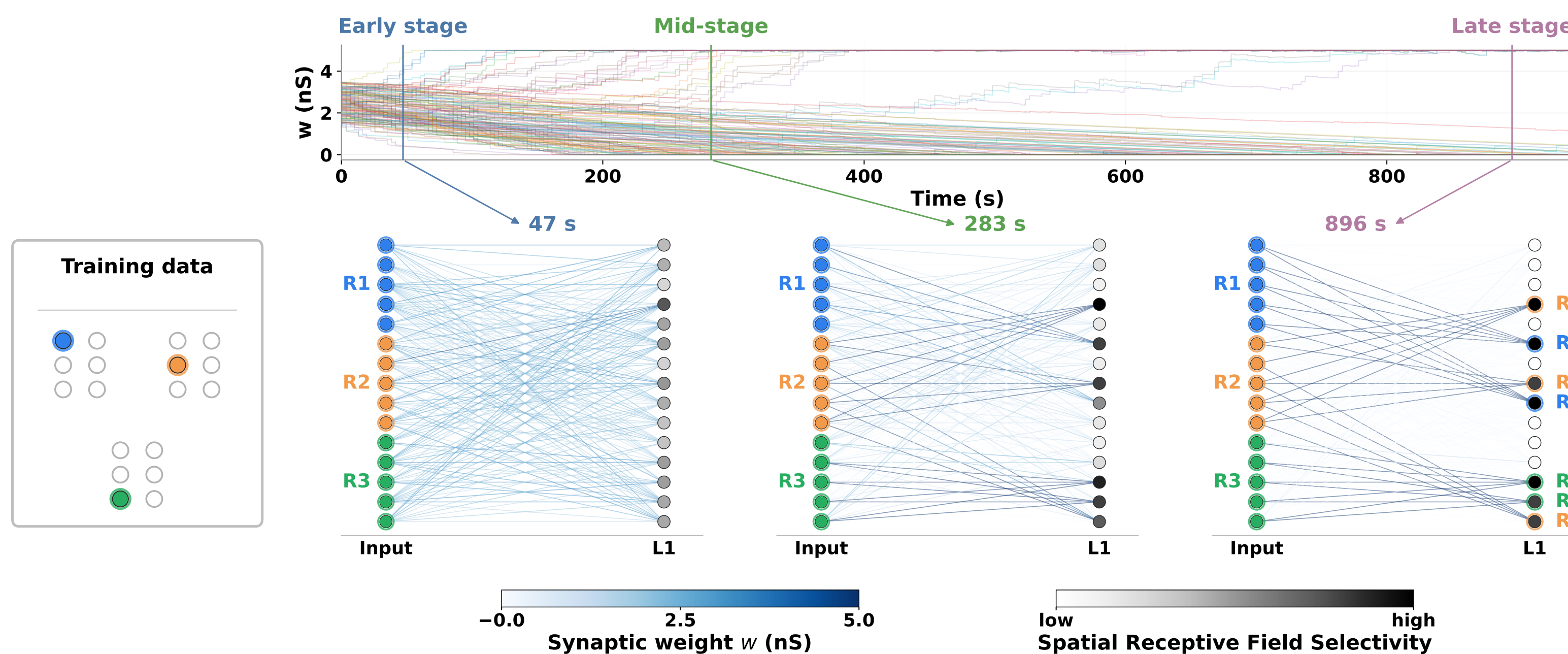
Fully local plasticity and event-driven computation support neuromorphic deployment.

Extension

Include top-down inhibitory feedback for hierarchical representation learning.

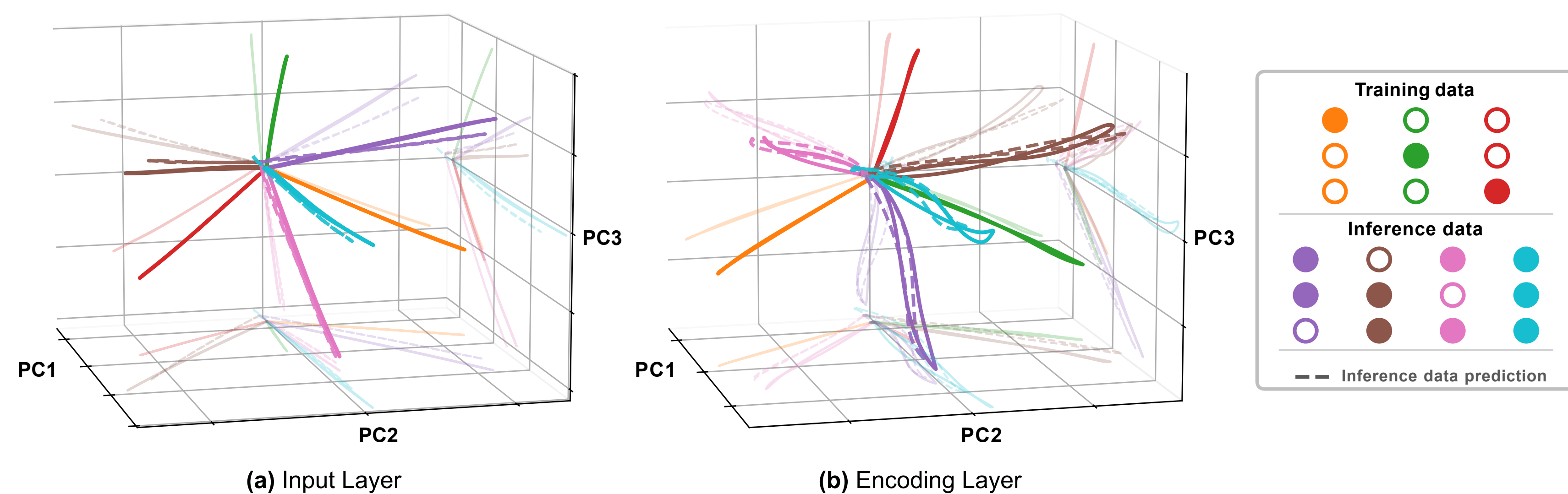


Spatial Braille task: Emergence of receptive fields



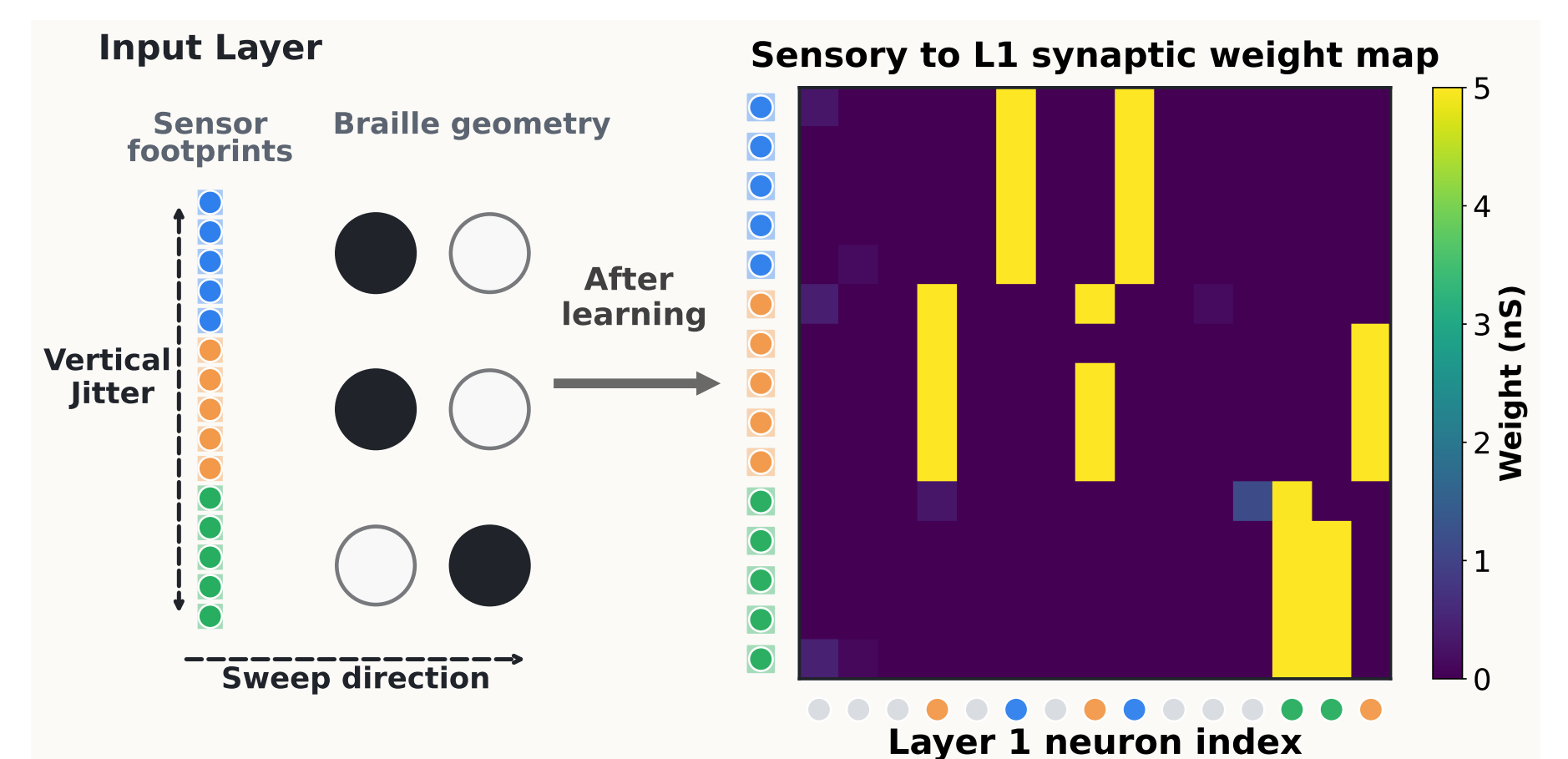
Local Ca-STDP self-organizes Braille-aligned receptive fields from initially unstructured connectivity. Initially diffuse synaptic weights progressively specialize to specific Braille rows, resulting in sparse and interpretable tactile representations.

Spatial task: Sparse code preserves discriminability



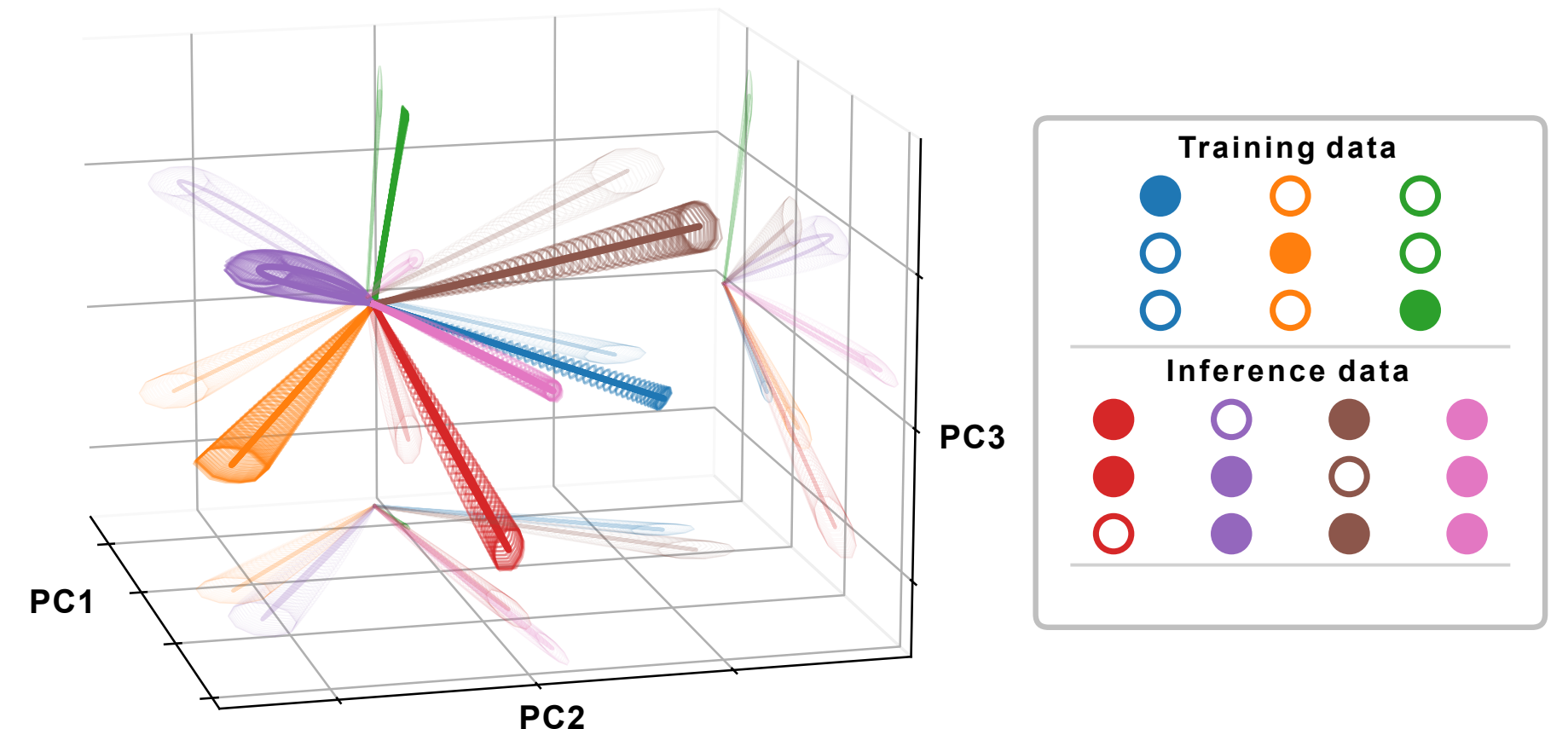
Sparse coding emerges without supervision while preserving Braille discriminability. Distinct Braille column combinations occupy well-separated trajectories in the learned state space.

Learned tactile encoder



Braille geometry emerges in the learned representation. The learned encoder preserves tactile structure using sparse Braille-aligned population activity.

Robustness to sensory variability



Training:

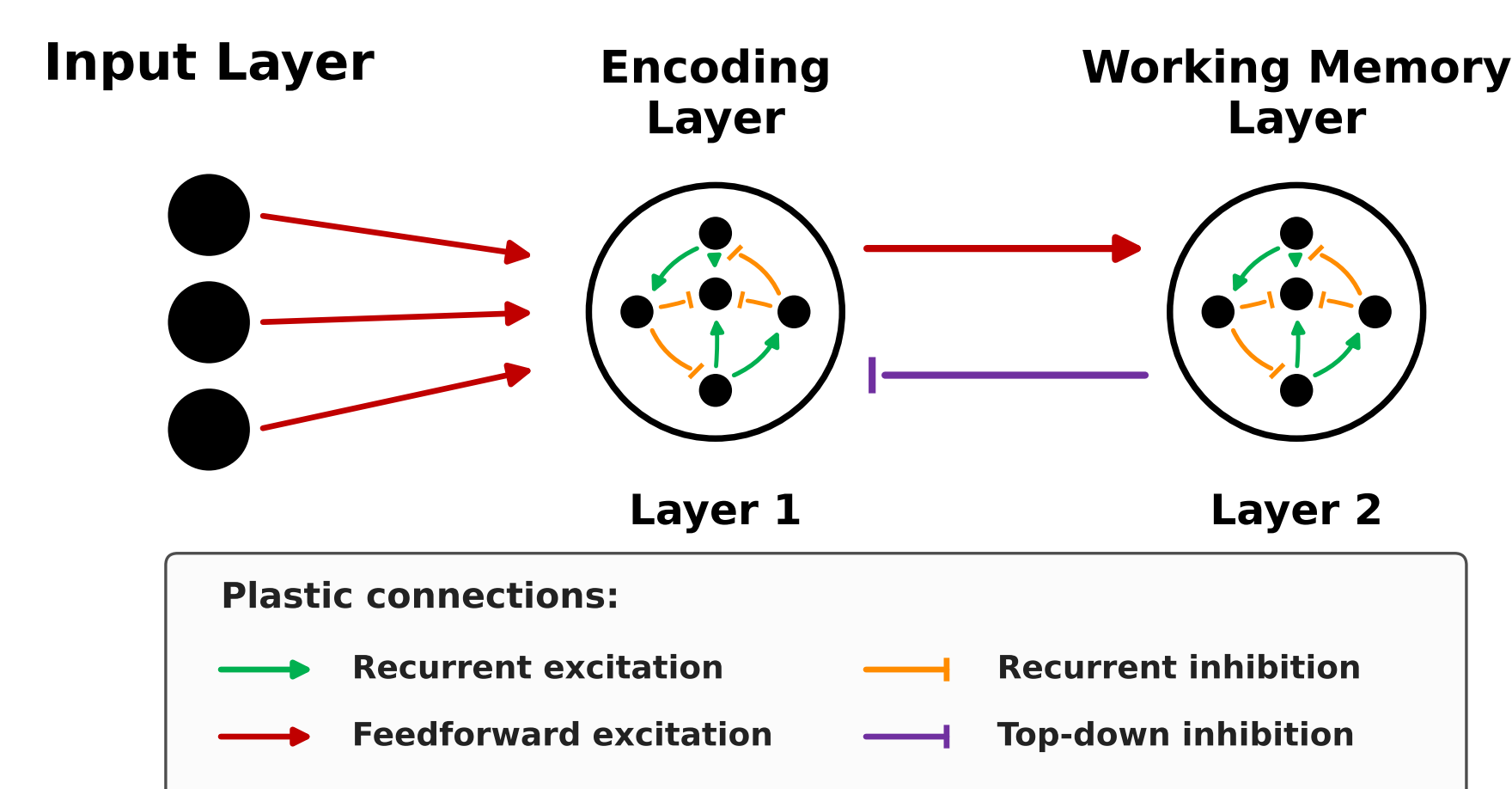
Vertical jitter with fixed simulated pressure sensor current (2 nA).

Inference:

Vertical jitter with variable sensor current (1 nA to 3 nA).

Learned trajectories remain well separated despite sensory variability.

From spatial encoding to temporal Braille reading



The sparse spatial encoder feeds a recurrent working-memory layer.

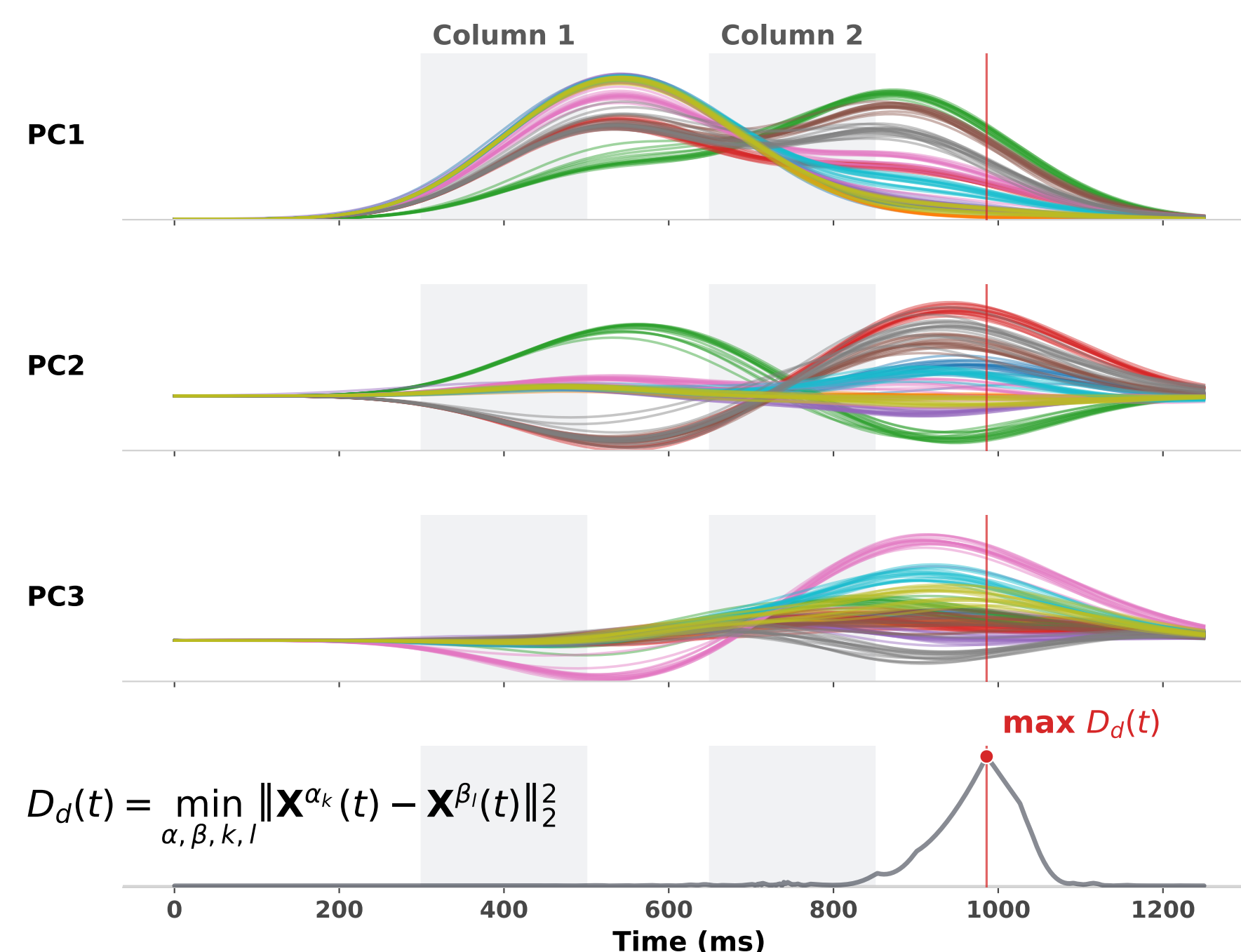
Task

Discriminate two-column spatiotemporal Braille patterns.

Mechanism

Balanced recurrent E/I dynamics generate and maintain a selective memory trace for spatiotemporal pattern discrimination.

Temporal trajectories reveal discrimination time



Training protocol

Training used 10 randomly selected Braille letters with vertical jitter and fixed pressure.

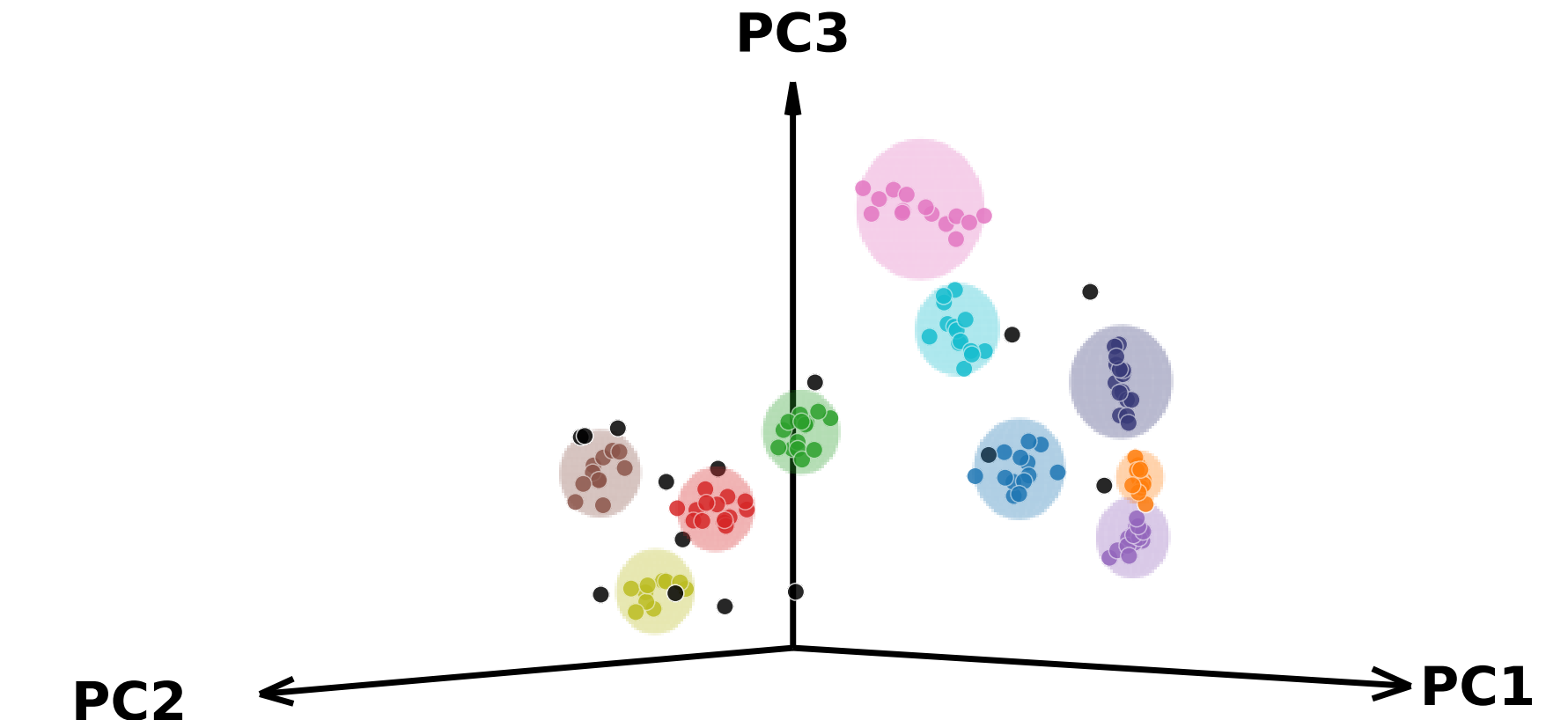
Neural trajectories

Different letter sequences follow distinct trajectories in PCA space.

Working memory

Maximum separation emerges only after information from both Braille columns is integrated.

Unsupervised clustering recovers letter identity



Cluster separation

Network states sampled at $\max D_d(t)$ form 10 compact, well-separated clusters.

DBSCAN decoding

DBSCAN achieves 90% accuracy across 20 inference trials per letter, with errors primarily due to outlier rejection under sensory jitter.

Key Takeaways

- Local plasticity discovers Braille structure without supervision.
- The learned representation preserves discriminability and generalizes to unseen patterns.
- Recurrent working-memory dynamics enable robust temporal pattern discrimination.