Efficient Neuromorphic Braille Discrimination via Spiking Predictive Coding

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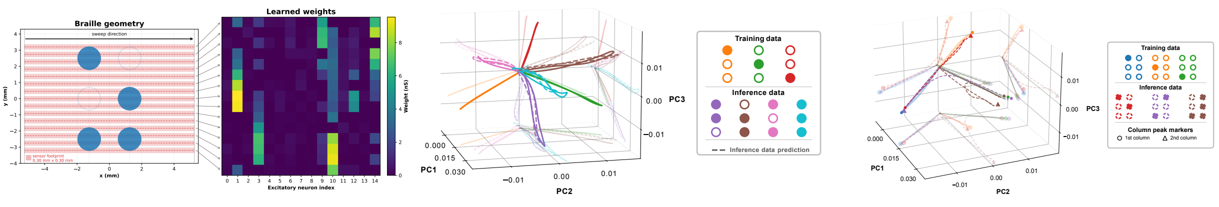
Neuromorphic systems leverage event-driven sensing and sparse, asynchronous computation, making them well suited for low-power applications. However, efficient learning remains a key challenge, as most approaches rely on supervised algorithms such as BPTT applied to SNNs, which are difficult to implement on analog hardware, rely on labeled data, lack biological plausibility, and are not well suited for continuous, online learning.

A recent spiking learning framework [1] based on predictive coding [2] addresses these limitations through unsupervised STDP and the emergence of sparse, structured receptive fields. However, its reliance on precise spike timing limits direct hardware implementation, motivating the development of alternative hardware-compatible learning mechanisms.

We propose an unsupervised predictive coding architecture for tactile spatio-temporal pattern discrimination, compatible with neuromorphic hardware. We evaluate it on Braille reading to assess transfer from vision-based predictive coding to the tactile domain. In contrast to supervised neuromorphic approaches [3], our method aims to achieve efficient, robust and structured representations with reduced network complexity.

The architecture consists of an input layer encoding tactile signals using an SA-like mechanoreceptor model, an excitatory Conductance-based LIF population, and an inhibitory pool providing feedback-driven competition, with learning governed by a calcium-based STDP rule [4]. Parameters were chosen within biologically plausible ranges to ensure balanced potentiation and depression matched to input activity, rather than tuned for performance.

Using a compact 45-neuron network (15 input, 15 excitatory, 15 inhibitory), less than one tenth of state-of-the-art models, the network is trained on simple dot patterns and self-organizes into robust and structured Braille-aligned receptive fields (see Fig. 1a). These representations generalize to the full alphabet despite never observing complete letters during training, while maintaining highly sparse neural activity. This generalization is illustrated in Fig.1b, where PCA is applied to the smoothed firing rates of the excitatory population. As shown in Fig.1c, responses to composite Braille patterns evolve as sequential transitions between representations of individual columns, indicating that unseen patterns are encoded through combinations of previously learned components.



(a) (b) (c)

Figure 1: Emergence of structured receptive fields and generalization to unseen Braille patterns. (a) Synaptic weights from the input layer to the excitatory population after unsupervised learning, showing receptive fields aligned with Braille dot structure. (b) PCA projection of the smoothed firing rates, illustrating separation and generalization to unseen patterns. (c) PCA trajectories for temporal combinations of columns, showing that responses to composite patterns follow transitions between representations of individual components.

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