

# From Temporal Statistics to Neural Realization: A Bio-Inspired Multi-Stage Coding Transformation for Dynamic Spike-based Olfactory Processing

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Processing dynamic sensory signals in a robust and hardware-efficient manner remains a fundamental challenge in artificial sensing systems. Existing approaches mainly follow two paradigms: traditional machine learning methods rely on static representations and do not naturally support temporal processing, whereas deep learning approaches enable event-driven computation but often depend on precise parameter tuning, which limits their robust deployment on mixed-signal hardware [1]. Inspired by coding transformations in biological olfactory systems [2], we hypothesize that sensory processing can be understood as structured temporal-statistical computation on spike trains within signal processing of spiking neural network (SNN). From this perspective, temporal statistics serve as an explicit computational substrate rather than descriptive features.

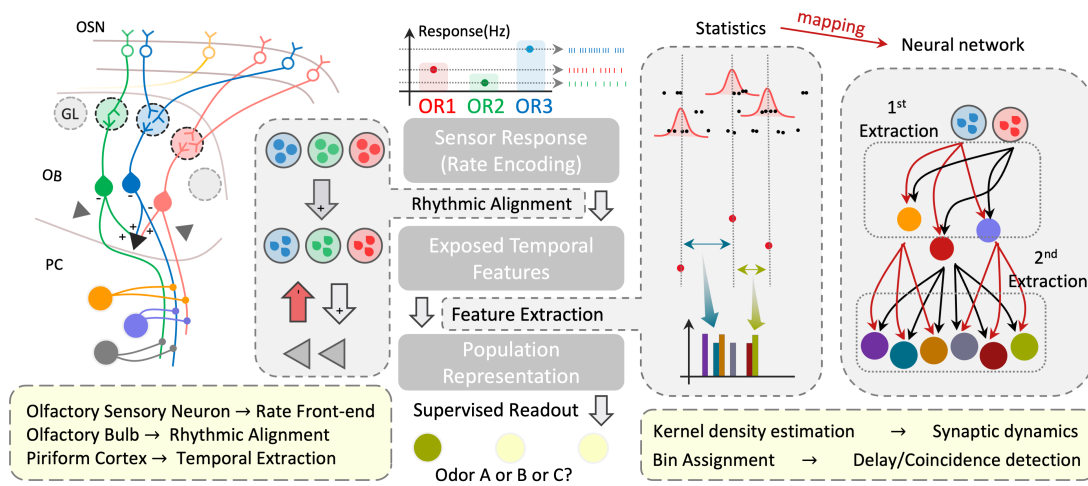


Figure 1: A unified framework that transforms spike-based temporal signals into robust population representations via explicit temporal-statistical processing and its neural realization.

Based on this view, we propose a bio-inspired, transformation-centric co-design framework in which temporal-statistical features are extracted and progressively organized into structured population representations. These transformations are further approximated via their neural realization using simplified spiking neural motifs, establishing a functional correspondence between statistical operations and circuit-level implementations.

Experiments on olfactory datasets show that the proposed representations effectively capture task-relevant information and can be approximated by spiking neural circuits while preserving performance. The resulting architectures exhibit robustness to temporal noise, device mismatch, and process variation, demonstrating their suitability for hardware-constrained sensory processing. This work provides a principled pathway from temporal statistics to neural realization for robust and interpretable spike-based olfactory processing.

[1] Muir et al., Nat. Commun., 16, 3586, 2025.

[2] Uchida et al., Annu. Rev. Neurosci., 37, 363–385, 2014.