# Topological Neural Data Analysis with Behavioral Constraint

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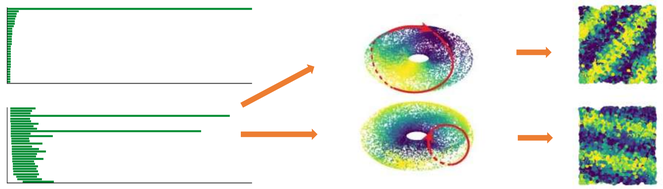
NEURAL INFORMATION PROCESSING SYSTEMS

## Topological Data Analysis (TDA) on Neural Data

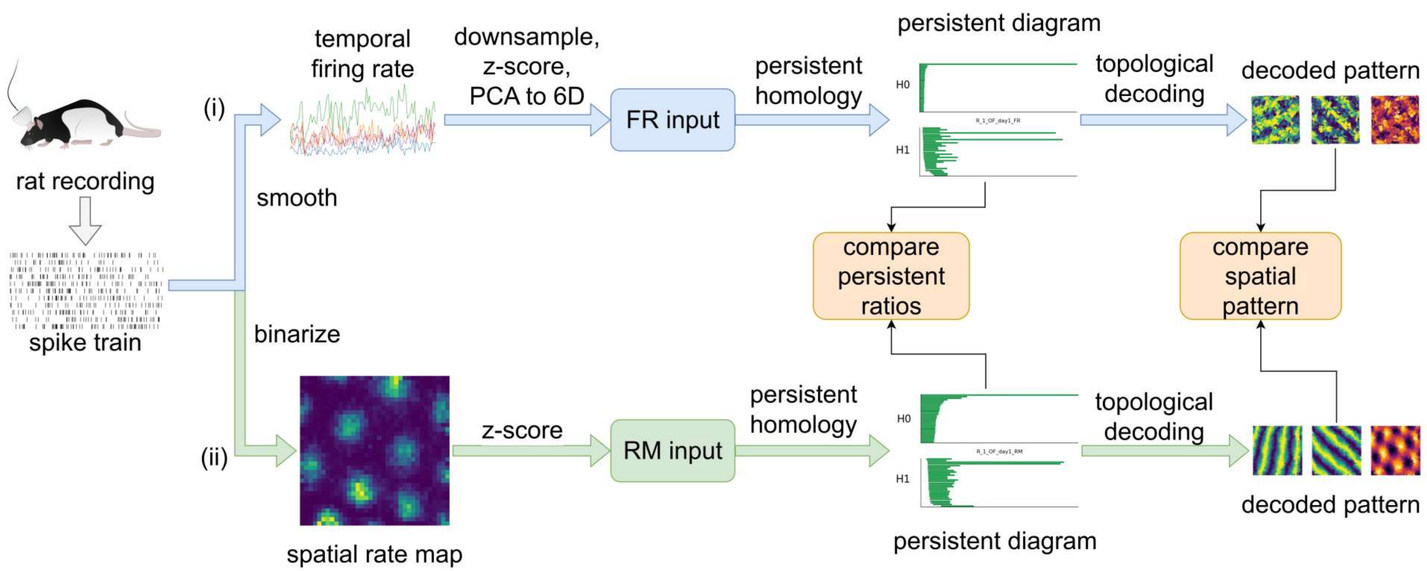
- A manifold perspective [1] of neural population activity
- Persistent (co)homology [2] identifies topological structures
- Decode topological signatures to behavior patterns



Current TDA pipeline [3]:

- Use temporal firing rate (FR) as input -> prone to noise
- Excessive preprocessing -> lower interpretability and reliability
- Real neural data deviates from standard topology -> hard to detect

## A Behavior-based Topological Data Analysis Pipeline

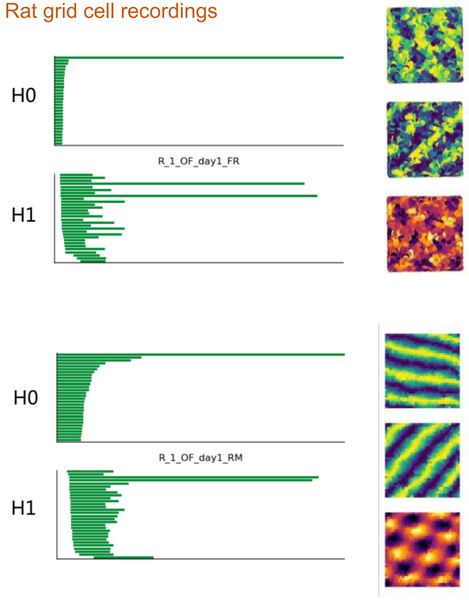



Our TDA pipeline:

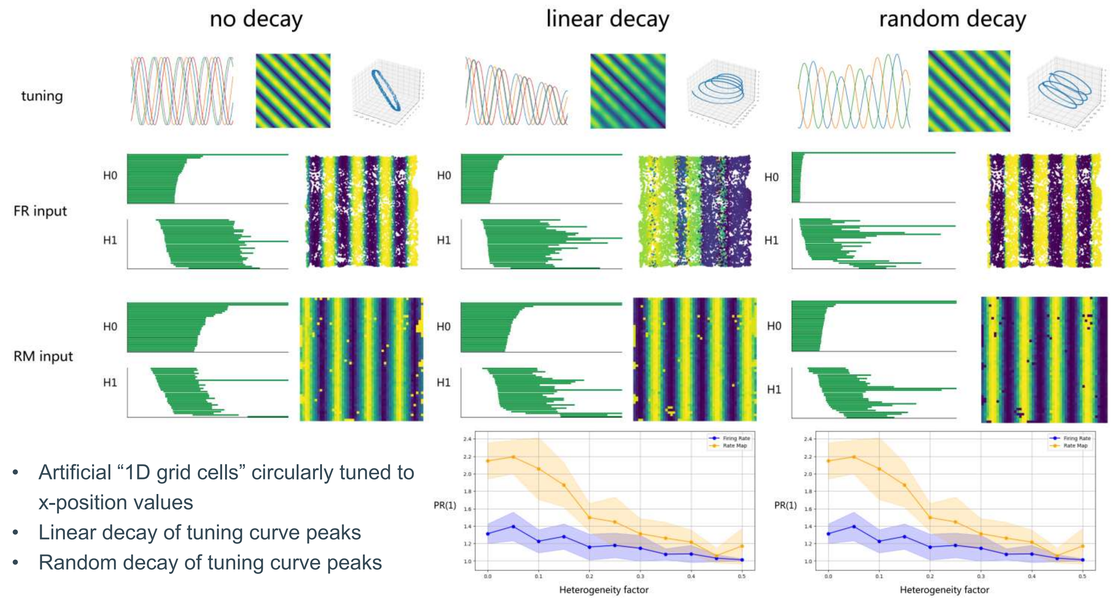
- Project temporal spike trains to spatial rate maps (RM)
- Only need z-scoring as preprocessing
- Adjustable spatial resolution, flexible computational cost

## Experimental Results

Rat grid cell recordings




Synthetic heterogeneous 1D "grid cells"

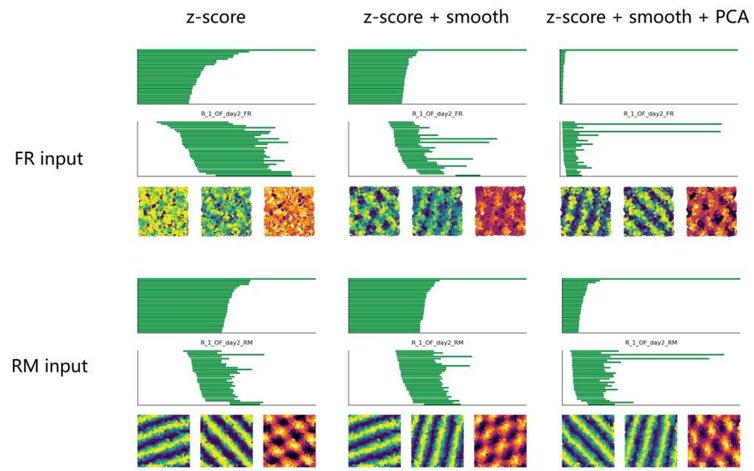



- Artificial "1D grid cells" circularly tuned to x-position values
- Linear decay of tuning curve peaks
- Random decay of tuning curve peaks

We defined "Persistence Ratio" $\mathrm{PR}(i)$:

- Persistent bar length means significance of the topological feature
- Number of dominant features (Betti number) shows topological shape
- $\mathrm{PR}(i)$: relative length of the i-th longest bar to (i+1)-th longest bar in dimension 1
- A large $\mathrm{PR}(i)$ means the topology is close to the product of i circles

Comparing robustness under different preprocessing steps




## Discussions

- Behavior-based TDA is more efficient, robust, and flexible
- Behavior-based TDA can better detect deviations in neural tuning geometry
- We aim to integrate topological and geometric data analysis to interpret these deviations
- We aim to test our method on other neural datasets

## Reference

[1] Matthew G. Perich, Devika Narain, and Juan A. Gallego. A neural manifold view of the brain. *Nature Neuroscience*, 28(8):1582–1597, August 2025.

[2] Afra Zomorodian and Gunnar Carlsson. Computing Persistent homology. *Discrete & Computational Geometry*, 33(2):249–274, 11 2004.

[3] Richard J. Gardner et al, Toroidal topology of population activity in grid cells. *Nature*, 602(7895):123–128, 1 2022.