

Application for Persistent Homology

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1 Introduction

This is a summary for the paper "toroidal topology of population activity in grid cells", which showed that the joint activity of grid cells from an individual module resides on a toroidal manifold, as expected in a two-dimensional continuous attractor network (CAN) [GHP⁺22].

2 Background

2.1 Grid Cells

Grid cells are a key component of the medial entorhinal cortex as a part of a neural system. They fire at regular intervals as an animal navigates an open area as shown in Figure 2.1 [HFM⁺05].

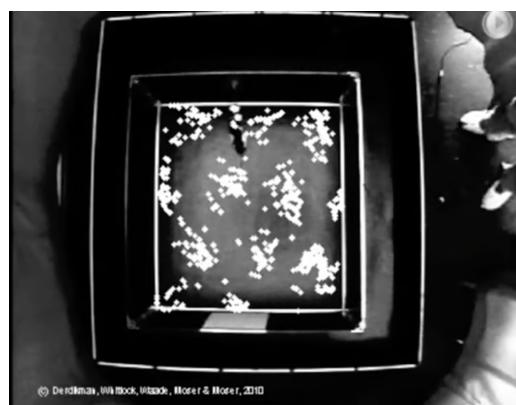


Figure 2.1: Firing pattern of a grid cell: when the neuron fired, a dot was placed in the location where the rat's head was.

*This is a course taught by Michael Lesnick from SUNY Albany.

2.2 Experimental Data Collection

The data were collected from three rats (Rats Q, R and S), and the rats were implanted with Neuropixels silicon probes [JSS⁺17, SAL⁺21] targeting the MEC–parasubiculum (PaS) region. Two rats (Q,R) were implanted bilaterally and the third rat (S) was implanted in the left hemisphere.

Individual modules are focused on because the grid cells in one module fire at the same time. Six grid modules (Q1, Q2, R1, R2, R3, S1) across all rats were identified.

There are three tasks for rats: open-field (OF) foraging task, wagon-wheel (WW) track foraging task and natural sleep, as shown in Figure 2.2

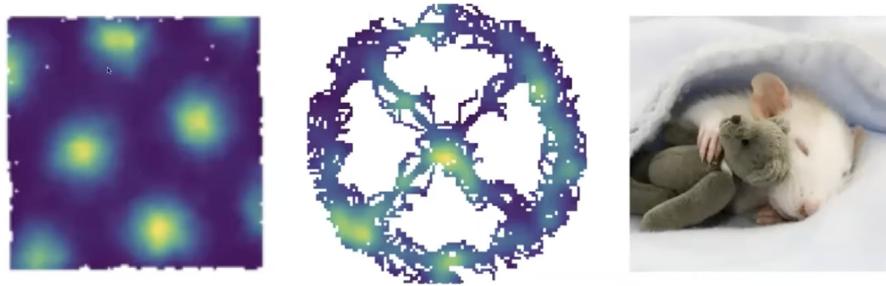


Figure 2.2: Three tasks for rats: open-field (OF) foraging task, wagon-wheel (WW) track foraging task and natural sleep.

Firing rates of 149 grid cells co-recorded from the module R2 are shown in Figure 2.3, as a function of rat position in OF arena.

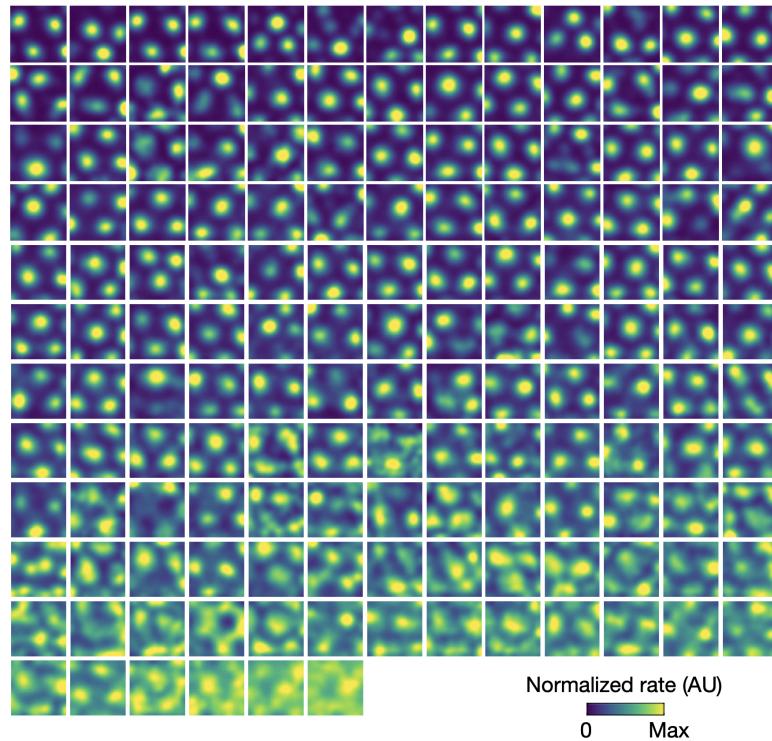


Figure 2.3: Firing rates of 149 grid cells from the module R2

2.3 Intuition from Data

As shown in Figure 2.4, individual grid cells have distinct firing fields that are repeating in two different directions. The repeated rhombus' opposite sides could be glued together to form a 2D torus, which suggests the toroidal representation of the single neuron.

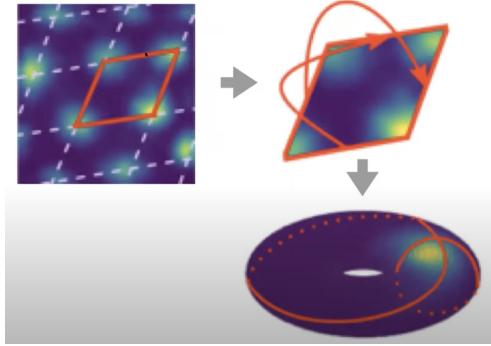


Figure 2.4: Grid cells in a box suggest a torus

3 Method

3.1 Pipeline

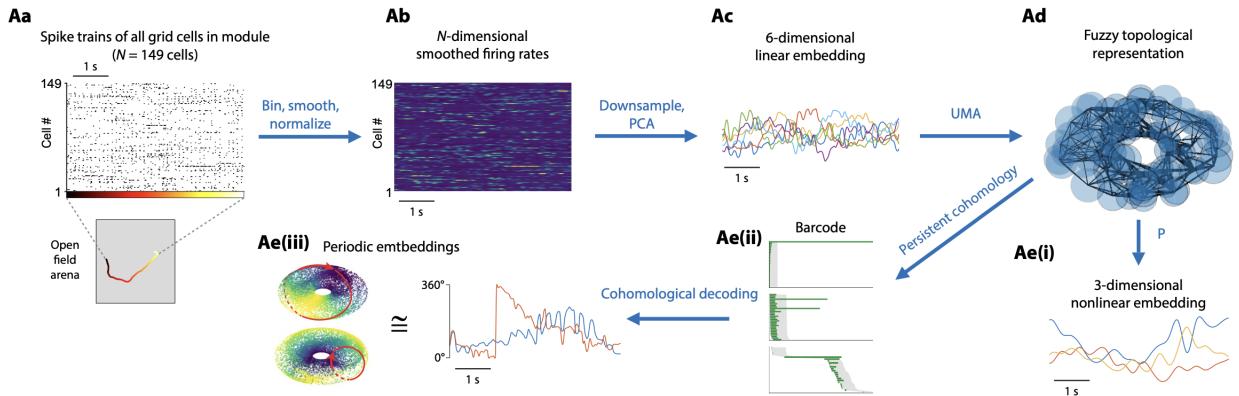


Figure 3.1: Pipeline for detecting toroidal topology: it is 5-second spikes from 149 grid cells of an animal foraging in an OF arena.

As shown in Figure 3.1, first the 5-second spikes from grid cells were recorded. Then the spike trains were binned in time (N bins) and then smoothed and normalized before downsampling from N dimensions to 6 dimensions using PCA. Furthermore, a fuzzy topological graph representation is constructed from the six principal components by UMAP. Subsequently persistent cohomology was applied to the fuzzy topological representation to obtain the barcode. As barcodes could not identify the space, the persistence cohomology results were further investigated with "cohomological decoding" procedure [DSVJ09] to get a two-dimensional projection of the original N -dimensional point cloud.

4 Results

As shown in Figure 4.1, barcodes indicate that toroidal topology of grid-cell population activity is independent from specific sensory inputs.

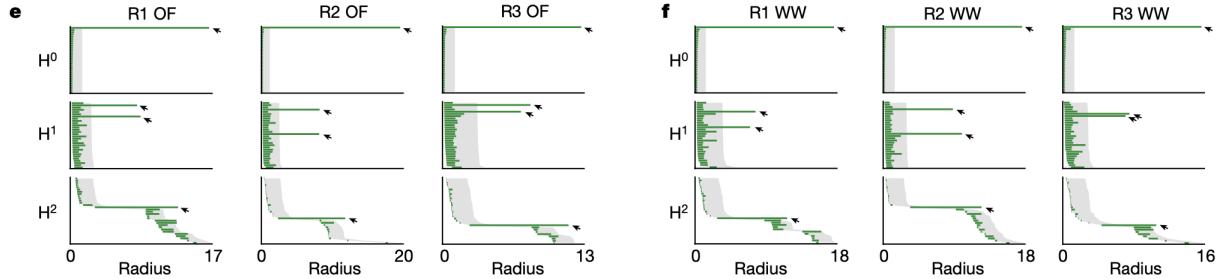


Figure 4.1: Barcodes from different sensory inputs.

After comparing the decoded trajectory and real trajectory, they found that toroidal representation captures the most variance in the data and even explains the single neuron activity better than the real world spatial representation.

References

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