A Persistent Homology Approach for Characterizing Honeybee Behavior during Food Exchange

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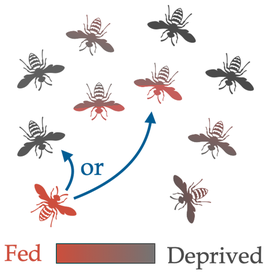
Introduction

- *Trophallaxis*, the direct transfer of food among nestmates in honeybees, serves not only as a feeding mechanism but also as a medium for information exchange among workers, helping them coordinate their tasks within the hive [1].
- We use topological data analysis (TDA) for characterizing the spatiotemporal patterns that govern the food exchange dynamics.

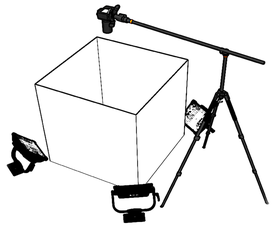
Main Research Question

- Can we distinguish different modes of collective food exchange in bees by analyzing the spatiotemporal patterns that emerge during the food distribution?



Behavioral Experiments

- Four different colonies of honeybees *Apis mellifera* L. are divided into two groups.
- One group is *deprived* of food for 24 hours before each experiment.
- The other group has constant access to food.
- These *fed* bees, which comprised 5-10% of the whole population in each experiment, are marked with a pink circle on their thorax.
- We put both groups of *fed* and *deprived* bees inside a 2D arena and record their interactions from the top.




Before fed bees

A: t = 0


After fed bees

B: t ≈ 6 minutes

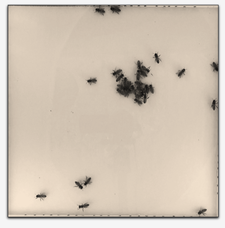

C: t ≈ 20 minutes

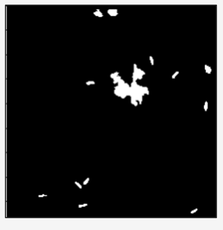
Experiments: Observations and Hypotheses

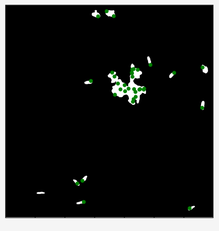
- We observed three regimes in our experiments
  - A. Individuals are distributed sparsely across the arena
  - B. Bees form dense aggregations
  - C. They get back to their sparse arrangement

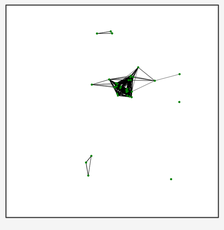
Topological Data Analysis

- is a general framework in applied mathematics to analyze and exploit the complex topological and geometric structures underlying data.
- This method is well suited for information extraction from datasets that are high-dimensional, incomplete and noisy.
- TDA has been successfully used to explore biological aggregations in recent years [2,3]
- The goal is to characterize a group's dynamics via the time-evolution of topological invariants called Betti numbers, accounting for persistence of topological features across multiple scales
- Our workflow is summarized in the four stages,


1. Frame extraction


2. Bee detection with Image segmentation


3. Point cloud generation


4. Simplicial complex construction

- Betti numbers are topological invariants measuring the number of *k*-dimensional holes in an object. β_0 : number of connected components, β_1 : number of topological circles, etc.

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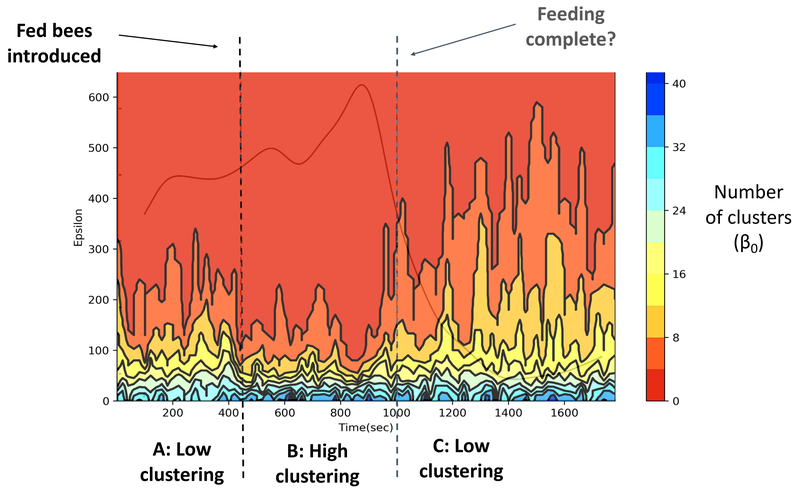
- represent the value of a Betti number as a function of time and topological proximity parameter ϵ.
- To track bees' aggregations, we consider the value of β_0 (i.e., number of clusters)



Results

- We show that TDA can pick up the clustering patterns in food exchange experiments.
- We apply change point detection technique to identify changes in the probability distribution of our timeseries.
- The first detected change point matches the time that the fed bees are introduced. We conjecture that the second change point corresponds to when the food distribution is completed.
- A high clustering regime that emerges between the two change points is a result of collective food exchange
- This pattern is consistent across multiple repetitions of the same density experiments.

Future Directions

- Extend this analysis to explore the dynamics in higher densities
- Evaluate the fit of our current trophallaxis ABM model presented in [4] to the experimental results we obtained using TDA, to validate and improve our model.

References

[1] Greenwald, E., Segre, E., and Feinerman, O. *Ant trophallactic networks: simultaneous measurement of interaction patterns and food dissemination*. Scientific reports, 2015.

[2] Ulmer M., Ziegelmeier L., Topaz C.M. *A topological approach to selecting models of biological experiments*. PLOS ONE, 2019.

[3] McGuirl, M., Volkening, A., Sandstede, B. *Topological data analysis of zebrafish patterns.* PNAS, 117 (10), 2020.

[4] Gharooni Fard, G., Bradley, E., & Peleg, O. *Data-Driven Modeling of Resource Distribution in Honeybee Swarms*. MIT Press, 2020.