On the Efficiency of Food Distribution Via Trophallaxis in Honeybees: An Agent-Based Model Approach

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UNIVERSITY OF COLORADO BOULDER

Golnar Gharooni Fard[1], Elizabeth Bradley[1,2], Charlotte Gorgemans[3] and Orit Peleg[1]

[1] Department of Computer Science, University of Colorado, Boulder CO, USA
[2] Santa Fe Institute, Santa Fe, NM, USA
[3] Boulder High School, Boulder CO USA

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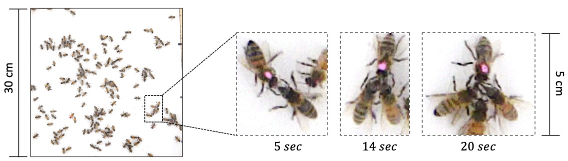
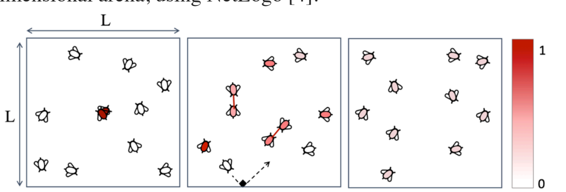
INTRODUCTION

- Cooperation and division of labor are the hallmarks of eusocial insect societies. Despite the apparent simplicity of individuals and the absence of central control, insect societies exhibit surprising degrees of complexity [1].
- *Trophallaxis*, the direct transfer of liquid food among nestmates in a honeybee colony, serves not only as a feeding mechanism but also as a medium for information exchange among workers, helping them coordinate their activities [2].
- We are interested in studying how simple, local rules, followed by all members of a honeybee colony, lead to effective global behaviors.



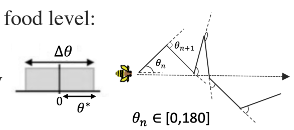
APPROACH

- A simple stochastic model of food exchange among self-propelled agents (i.e. individual bees) [3] moving and interacting in a two-dimensional arena, using NetLogo [4].



MODEL DETAILS

- Bee agents motion is a modeled using Correlated Random Walk (CRW)
- States of each agent:
  - *available*, it is ready to initiate a food exchange interaction if it encounters another agent
  - *busy*, it is currently involved in a food exchange and cannot initiate another one
- Agents are categorized based on their initial food level:
  - *donor*: $f_i(0) = 1$, initially centered
  - *receiver*: $f_i(0) = 0$, scattered randomly
- Density of the agents in the arena: $\rho = \frac{N}{L \times L}$



- At each time step, available agents modify their previous heading by $\Delta\theta$ drawn from a uniform distribution and take a step of length one in the new direction [5]
- The model stops when the food is distributed evenly among all agents. This is set by checking food variance at each time step:

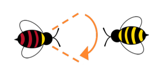
$$\sigma^2(n) = \frac{\sum_{i=1}^{N}(f_i(n)-\mu)^2}{N}$$

SPECIFIC RESEARCH QUESTIONS

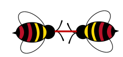
- How do the density of the bee-agents, and the geometry of their random walk, influence food distribution?
- What is the relationship between trophallaxis events and distribution time scales?

RULES OF THE MODEL

1. Take a random walk step (angle parameter θ^*)

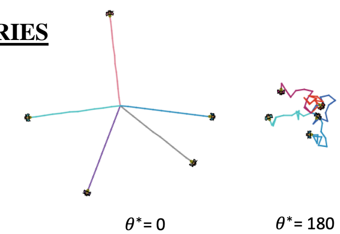


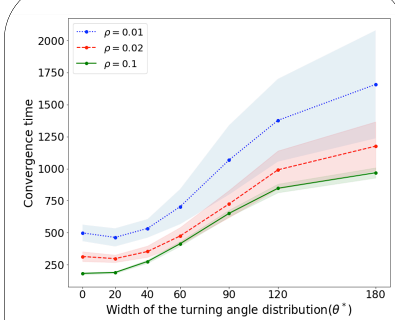
2. Check for encounter (based on a distance parameter)
3. Exchange food: $f_i(n+1) = f_i(n) \pm \frac{\Delta f(n)}{2}$



4. Loop until the food distribution is uniform:
   - Convergence
     - $\sigma^2(n) \leq \sigma^2_{threshold}$
     - $\sigma^2(n+1) - \sigma^2(n) \leq \Delta\sigma^2_{threshold}$

TRAJECTORIES



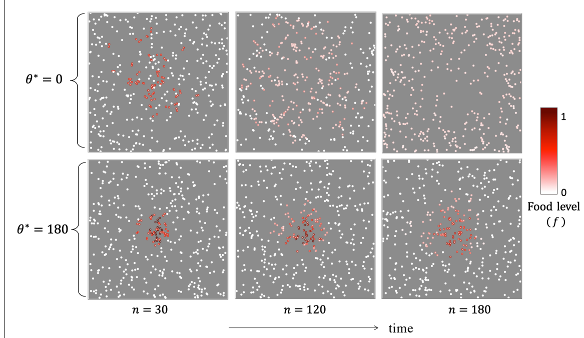


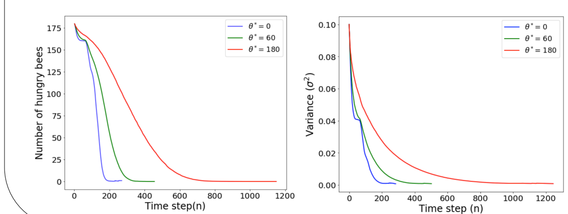
Effects of density:

- Higher density (ρ) encourages faster convergence rate, especially for lower θ^* values.

SPATIOTEMPORAL ANALYSIS

Simulations performed with 360 receiver bees ($\rho = 0.1$) distributed randomly through the arena and 40 donor bees initially located at the center.





Low turning angle:

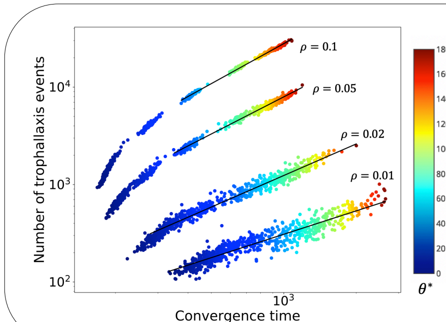
- Lower encounter probability
- Longer distance between exchanges
- Faster spatial distribution of food

High turning angle:

- High density of exchange encounters near the initial location of the donor bees
- Slower convergence
- Less-efficient distribution

Temporal patterns:

1. The number of hungry bees gradually decreases over time
2. The variance of the food decreases over time, leading to more even food distribution



Scaling relationships between number of trophallaxis encounters and convergence time:

Density (ρ)	Slope of the scaling region
0.1	1.37
0.05	1.27
0.02	1.08
0.01	0.80

CONCLUSIONS

- Higher densities and lower turning angles lead to broader, faster food distribution
- Convergence time scales with the number of trophallaxis events
- Experiments underway to validate model parameters and results

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Golnar.gharoonifard@Colorado.edu