In-nest information flow analysis of social ant colonies

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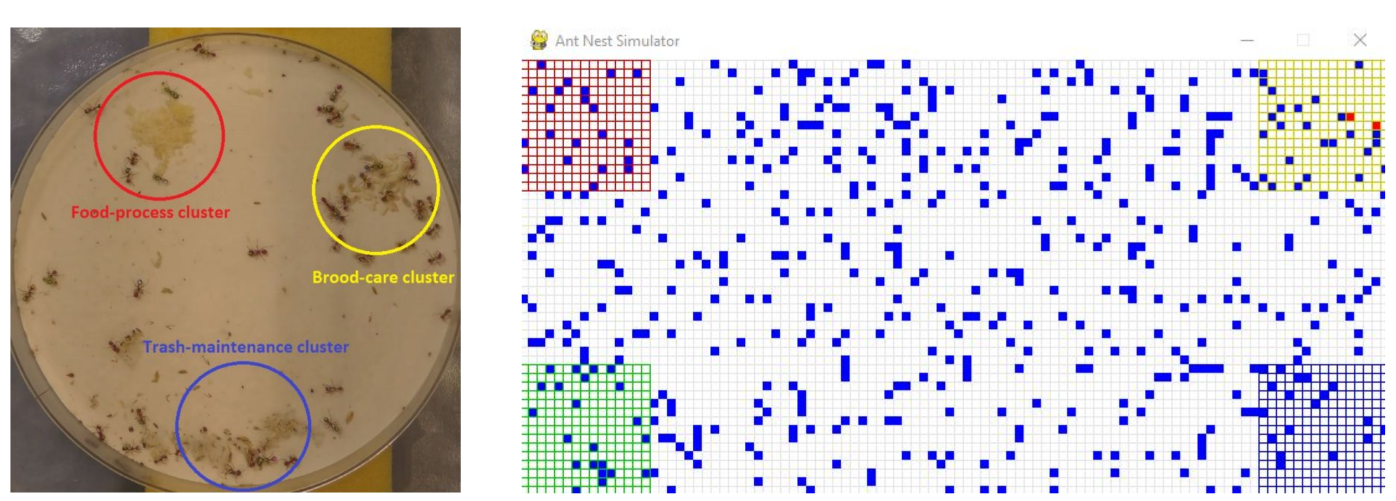
Introduction

Social insects can communicate in a number of ways, but the primary two that we seek to study are antennation and trophallaxis. These are both communication methods that rely on physical contact (as opposed to indirect information transfer via pheromones).

We are interested in how ant colonies as a whole process information. That is, if a single ant becomes alarmed by some stimuli such as a food or an enemy, how effectively do they transfer this information and how is this process affected by variables such as a worker allocation, population density, and nest structure.

Previous Work

Existing models studying this topic are typically agent based and include some assumptions about how workers distribute themselves. A **Spatial Fidelity Zone (SFZ)** is an area of the nest dedicated to a particular task. Workers engaged in a task tend to gravitate towards their associated SFZ.



Model from 'Dynamics of social interactions, in the flow of information and disease spreading in social insect colonies'

Above is a discrete time model on a grid with ants occupying individual grid cells and moving around based on their assigned task and the location of the task zones in the corners. All workers are given a task but only some will walk directly towards their task zone. The proportion of workers which do this is the **Spatial Fidelity** of the task.

The original paper studied how varying spatial fidelity effects the contact rates between task groups and within task groups. The goal of our work will be to look at these metrics in addition to others as we vary not only spatial fidelity but also the shape of the boundary.

All existing models assume a simple nest shape such as a square or circle, but in reality, these alarm responses will travel through nest features such as narrow tunnels, loops, chambers, and a large variety of shapes which may have different information flow dynamics.

Our Model

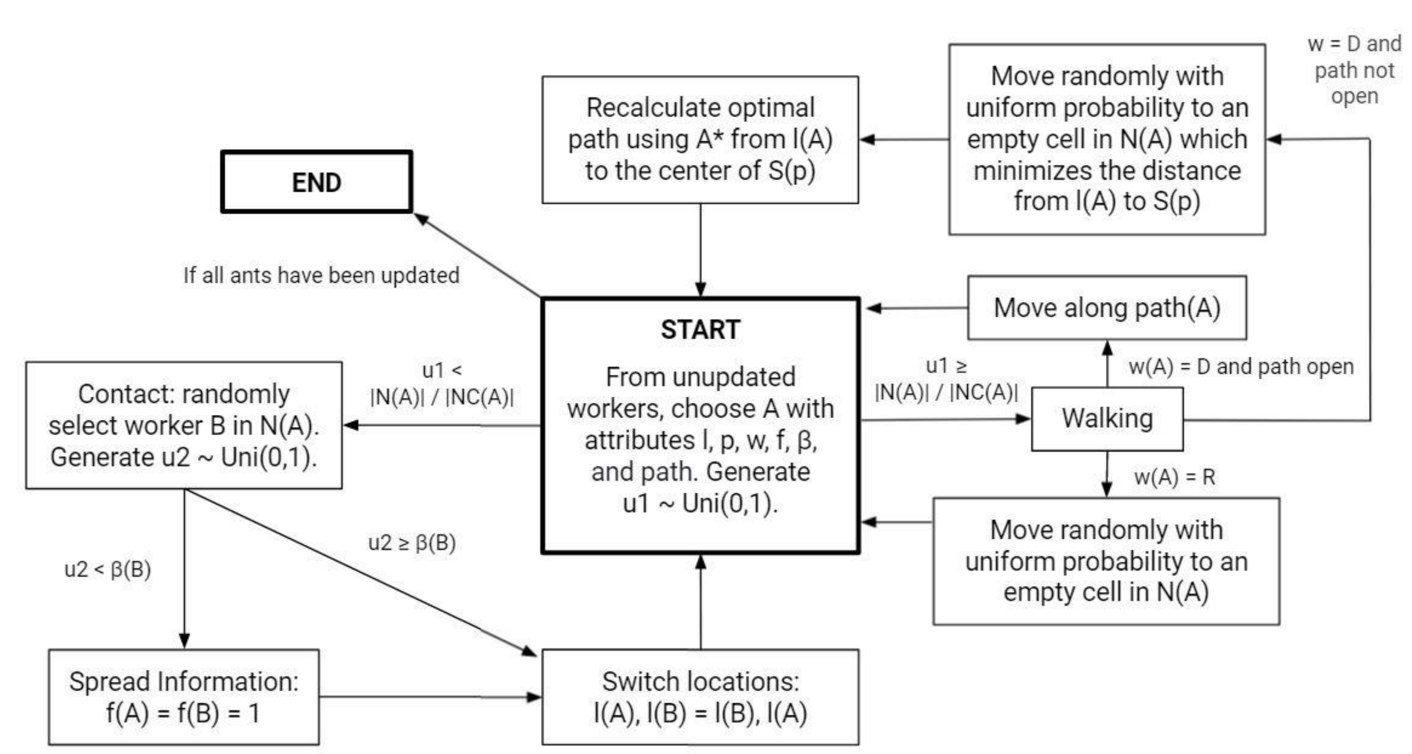
We constructed a model based on the discrete-time agent-based based model by Guo et al. The primary change was the change in the movement system for individual workers. Previously, an worker would walk towards its task zone by moving to their neighboring cell which minimized its distance to the task zone. With non-convex boundaries however, this can result in unrealistic behaviour such as workers running into walls and getting stuck. We fix this by calculating a path with A*.

The nest as a whole is described as a connected domain X in $\mathbb{Z}\times\mathbb{Z}$.

An individual worker A is characterized by six attributes:

- Location: $l(A,t) = (i,j) \in X$, Von Neumann Neighborhood $NC(A,t)$
  $N(A,t) = \{B : l(B,t) \in NC(A,t)\}$
- Task: $p(A,t) \in \{1, ..., P\}$, $p(A,t) = p(A,0)$
- Walking Style: $w(A,t) \in \{R, D\}$, $w(A,t) = w(A,0)$
- Information Status: $f(A,t) \in \{0,1\}$
- Information Receptiveness: $\beta \sim Uni(0.3, 0.7)$
- Path: $path(A,t) \subset X$ Shortest sequence of cells to the center of SFZ S(p)

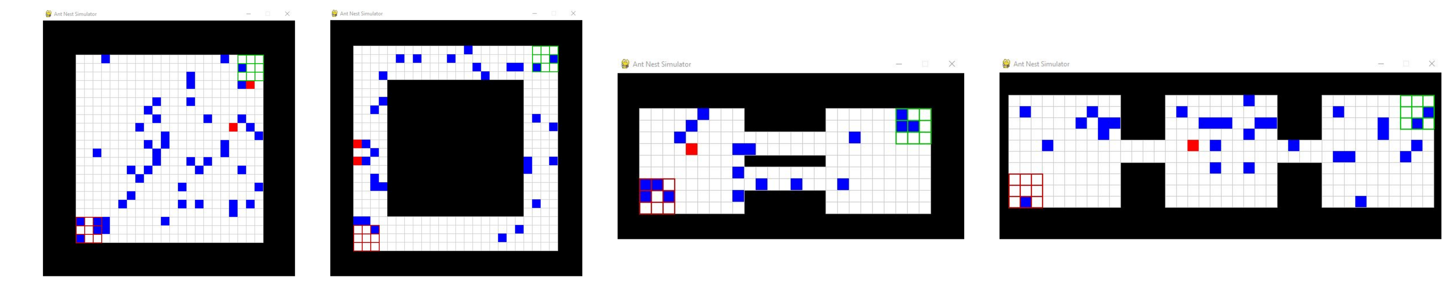
To start a simulation, the nest is populated with N uniformly distributed workers with walking styles dependent on the desired spatial fidelity. A single worker will start informed (f = 1) and all others are uninformed (f = 0). Each time step, all ants will follow the update step below:



During simulations, we track the total number of informed ants, the number of contacts between and within task groups at each time step, the Spatial Heterogeneity Degree (a measure of variance in worker locations), and motif counts in the time-aggregated interaction network of the workers.

Simulations

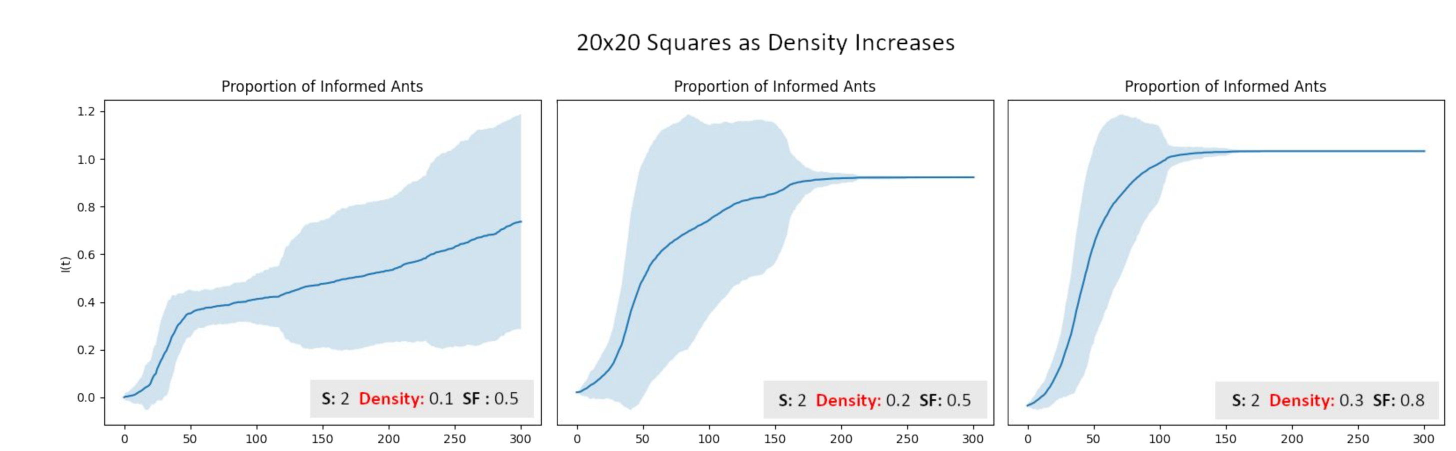
We averaged 30 simulations with 300 times steps each for a number of initial parameters. We tested each of 0.1, 0.2, and 0.3 densities, 0.2, 0.5, and 0.8 spatial fidelities on three different shape variations of squares, donuts, tunnels, and chains.

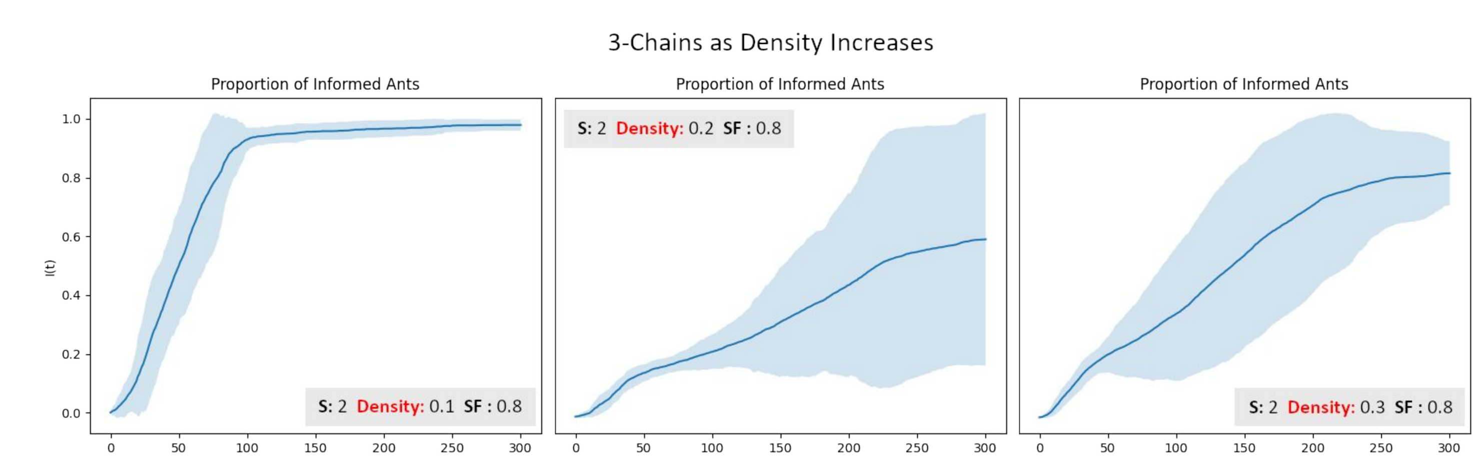


Examples of square, donut, tunnel, and chain simulations

Results

We noted several general trends that were interesting. One I'll discuss here is the inverse effect of density on squares and chains.





For squares, increasing the density has the expected effect on the rate at which the worker population becomes fully informed; more workers help to spread the message faster. With chains, the opposite seems to happen. With an increased number of workers, the narrow passages between chambers become more difficult to navigate. This causes the flow of workers through the tunnels to slow, in turn slowing the spread of information.

We are currently working on quantifying some of these trends to make predictions about information flow dynamics in nests built from combinations of these features.

SACNAS National Diversity in STEM Conference (October 25 -29)

Xiaohui Guo, Jun Chen, Asma Azizi, Jennifer Fewell, and Yun Kang. Dynamics of social interactions, in the flow of information and disease spreading in social insects colonies: Effects of environmental events and spatial heterogeneity. Journal of Theoretical Biology, 492:110191, 2020.