Independent Project: Agent Based Model of Collective Decision Making by T. Albipennis Ants

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ABSTRACT

When a nest containing a colony of Temnothorax albipennis ants is destroyed, this colony has to quickly find a new nest to live in. In nature, the ants do this by having a subset of the workers explore the surrounding area for new nests, make a decision, and move the colony to the new nest. Observations of the ants, like those done in [1], [3], and [4], can be used to inform model simulations. In this paper, an agent based model of the ants' behavior is used to simulate this decision. With the limited trials done, almost all simulated colonies successfully found the better of two different quality nests, although in simulations with three available nests sometimes they would decide on a mediocre instead of the best available nest. This simulation can be used to explore the effect different behaviors have on the ants' distributed choice.

0. AUTHOR CONTRIBUTION

Model simulation code was written by Alex and partly reviewed by Nathan. Report was written by Nathan and reviewed by Alex except for the methods section which was written by both. All figures except for figure 1 were generated by Alex. Labels on figures 2, 3, and 4 were made by Nathan. Report formatting and graph integration done by Alex and reviewed by Nathan.

1. INTRODUCTION

The ants of Temnothorax albipennis (previously known as Leptothorax albipennis) often have to move nests after their current nest deteriorates or is destroyed. These relatively small colonies (typically under 500 workers [3]) need to decide quickly to find a new nest to move into. A subset of the colony is "charged" with finding prospective nests, deciding which nest to move to, and executing the move. This decision is made in a decentralized way, with each individual ant using relatively simple behaviors and local knowledge to contribute to the collective decision. In fact, the majority of the deciding ants do not assess all possible nests before committing to a particular new nest.

There are a variety of behaviors these ants use to in the course of this process. Besides an area search similar to a correlated random walk, the ants use, nest quality related commitment timing, tandem walking, direct transportation, and quorum sensing. When an ant chooses a new nest to recruit other ants to, she waits a period of time proportional to the quality of the nest (higher quality makes for a faster choice). In tandem walking, an ant leads another ant to a new nest. Direct transportation has an ant picking up another ant or brood item and move it to a new nest. Quorum sensing is used at the new nest to decide whether to tandem walk (low population at nest) or carry (high population at nest) ants to the new nest.

This paper describes an agent based model of the colony migration decision of the T. albipennis ants. This model is inspired by both the observations and models found in [3] and [4]. While it tries to incorporate all of the observed behaviors, there are some simplifications made (e.g. ants cannot get lost, no reverse tandem walks). Also, the agents used in this model are in a simulated grid containing the ants and the nests, as opposed to a probabilistic representation of the ants searching through their environment at predefined rates.

The rest of this paper is organized as follows. In section 2 we describe some of the related work in the area of T. albipennis nest decision. Section 3 describes the method of the agent based model used by the nest decision simulation. The results of two different simulation trials are described in section 4. Finally, section 5 has a brief discussion of the results seen and methods used.

2. RELATED WORK

There have been various studies into the behavior of T. albipennis and how the ants collectively choose nests. Direct observations of the ants in [1], [3], and [4] are used to identify the different types of behaviors individual ants when the colony needs to find and choose a new nest. The rates of these behaviors are also estimated in these papers.

In addition to these observations, [3] and [4] both propose and implement computerized modeling of nest choice. In [3], the authors use observations for a colony with one new nest to create a simplified model of a colony choosing between two new nests. In particular, they try to find the effect quorum size has on the process.

A more detailed agent based model is the focus of [4] and is one of the main inspirations of this papers agent based model. Again, observations of one colony evaluating and moving to only a single nest were used to estimate behavioral parameters. The model was tested with single new nest and double new nest situations and was found to match observations fairly closely in most situations, although it did not entirely predict how nest splitting happens.

Finally, in [2], the authors make a comparison between the albipennis ants and apis mellifera bees during their respective decisions and note similarities between the two species' decision process. These two species decision processes are

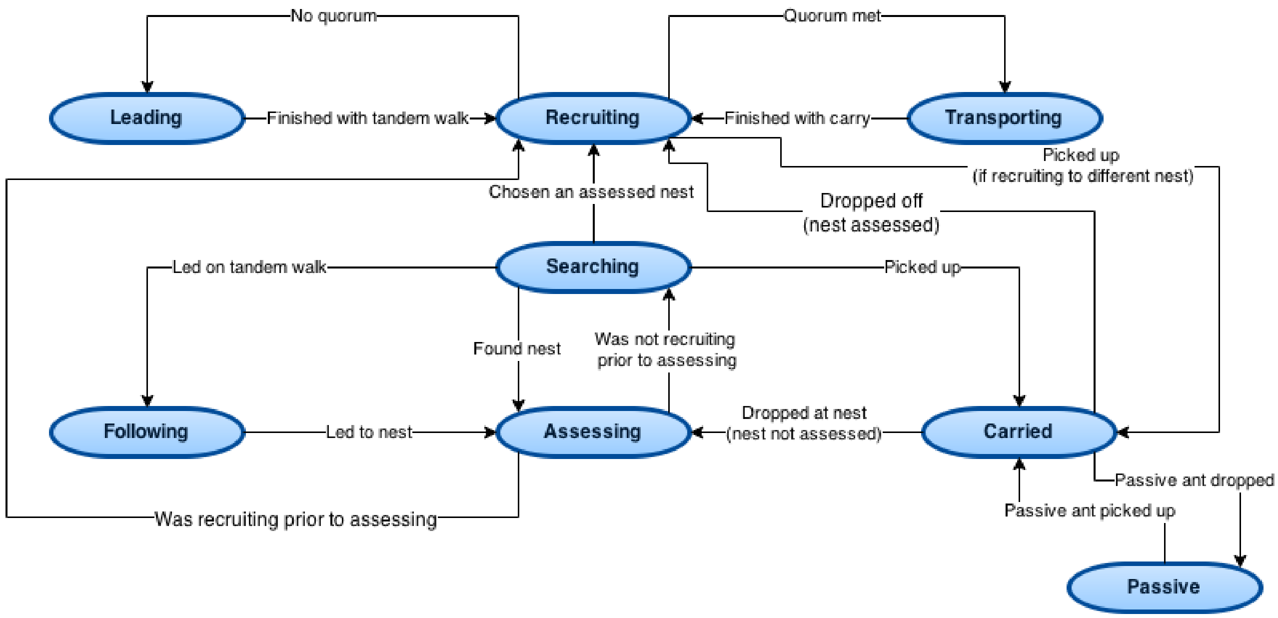


Figure 1: Two example runs of CA timestep diagrams

also compared to the optimal diffusion model decision process. While there are commonalities to the optimal process, the ants' decisions are unlikely to be equivalent to the optimal.

3. METHOD

In this model, there is a colony of ants located in a nest that has been "destroyed". This nest is located within a simulated hexagonal grid with one or more new prospective nests that the colony can choose from. As a result of the decentralized nature of the decision, the primary component of the model is the behavior of an individual ant. Each individual ant has behavior states that it can transition into when the correct conditions are met. Figure 1 shows the behavior states and the transitions that can occur to change the behavior state. This figure shows the overview of an ant's behavior, but the explanation of each transition is more thoroughly described below.

3.1 Ant Behavior

3.1.1 *Passive*

Passive workers are those ants that are like brood items and a queen, which do not participate in the decision making process. Instead, they stay within their current nest until they are carried by a transporting ant. Although their behavior is not essential for the model, they likely do perform some important tasks for the colony, guarding and taking care of brood and queen, for instance.

3.1.2 *Searching*

All ants that will be making the decision of the new nest, all start out in the searching state, since old home is initialized as destroyed. While searching, the ant will use a variant of random walk to look for new nests. Once a searching ant visits an unseen nest site, she will switch to the assessing behavior. Ever so often, the searching ants will go back to their destroyed home nest for a short amount of time to see if other recruiting ants want to lead tandem walks or perform transports.

In order to maximize the searching area, a variation of a random walk is used by the searching ant. Whenever an ant is doing a random walk she starts with a direction (d). At each time step, a randomly chosen delta from the range $[-\frac{\pi}{6}, \frac{\pi}{6}]$ is added to d. After a certain number of steps (n) or if she hits an obstacle, a totally new d is chosen at random from range $[0, 2\pi)$. Also at this time, a new n is chosen at random from the range $[5, 25]$.

When a searching ant meets a worker that is recruiting to a new nest, the searcher will follow the recruiter or allow herself to be carried. Finally, if a searching ant has assessed a nest, she will eventually choose to stop searching and start recruiting. This switch to recruitment happens at after a number of time steps, which is inversely proportional to the quality of a nest. This period allows for the ant to find a better nest and change her mind.

3.1.3 *Assessing*

When an ant is assessing a nest, she spends some time moving around the new nest. Unlike in physical ants, this movement is not directly needed for the ant to determine the quality of the nest. Rather it is done to mimic the timing that might be useful for quorum sensing. While assessing, the ant does not allow other ants to recruit her. After she is done assessing and she has never recruited to a nest, the ant will return to the searching behavior and wait until she chooses to start recruiting.

If the assessor has ever been a recruiter, then she will transition back to the recruiter. In this case, if the newly assessed nest is inferior to her currently chosen site, she will start recruiting from the newly assessed nest to her chosen site. If instead the newly assessed nest is superior to her chosen nest, then she will do the opposite; recruit from her old choice to the newly assessed nest. This behavior helps to rectify any colony splitting that might occur.

3.1.4 Recruiting

After choosing to recruit, an ant will try and find another ant and bring or lead her to the chosen nest. The two ways this happens is with leading (tandem running) and transporting. If the recruiting ant has not witnessed a quorum of ants at the chosen nest, then she will try and use tandem runs from searching ants from the old nest to the chosen nest. If a quorum has been witnessed by the ant at the chosen nest, then she will directly pick up any ant and bring them to the chosen nest, unless it is a worker recruiting to the same nest. This quorum is only checked when the ant is at her chosen nest and she has not witnessed a quorum yet. After leading or carrying an ant to the new nest, the recruiting ant will go back to the old nest to try and recruit more ants there or any other ones she will meet on the way.

3.1.5 Leading & Following

An ant that is leading moves towards her chosen nest. After a single move, she waits for her follower to catch up. The follower, in turn, always moves towards a leading ant and trying to stay in a position adjacent to the leader. When reaching the destination nest, the leader transitions back into recruiting behavior. When the follower reaches the new nest, if she has not seen the nest before, she will switch to the assessing behavior, but if she was recruited during time she was waiting to commit to the nest she will also immediately switch to recruitment.

3.1.6 Transporting & Being Carried

The overall structure of transporting and being carried is similar to the leading and following states. The main differences are the types of ants involved, the speed at which the ants move in this state, and the allowable transitions. Only searching workers can be lead in tandem, where any other ant can be carried. While transporting, the ants are also much faster than tandem walking because the leaders do not have to wait for their followers to catch up.

If the ant being carried was one of the initial passive section of the colony, then she will return to being passive. If the ant is an active worker and she has not seen the new nest, she will start assessing the nest. Finally, if the ant is an active ant and has seen the nest before, then she will start recruiting to whichever nest she currently believes is the best.

3.2 Directional Walking

In this model we used a square grid where each cell is shaped as a hexagon with six adjacent cells containing open cells and cells containing unpassable objects. The line of sight of a real ant is fairly limited and to mimic this in our model, the simulated ants only have an approximate bearing of where her destination is. This fact eliminates the ability to fully plan her entire route from the beginning, making object avoidance and path finding somewhat difficult. In particular, it is hard to prevent ants from getting stuck in the environment without ability to get out.

Whenever an ant encounters an obstacle in her path, she checks if she can move in both $\delta = \frac{\pi}{6}$ and $-\frac{\pi}{6}$ adjusted angle of the direction she is moving in and she chooses the one that gives her ability to move. Decided δ adjustment is recorded and is added to direction in all subsequent moves whenever there is still an obstacle. After every successful movement angle is decreased by a delta divided by a random number chosen from range $[1, 10]$. Algorithm described above can put an ant into a continuous circular motion upon hitting an obstacle, which is solved by resetting the direction whenever δ goes outside of $[-2\pi, 2\pi]$. Every movement attempt at each time step has also a random number from $[-\frac{\pi}{6}, \frac{\pi}{6}]$ range added to the direction, in a similar fashion that it is done in a random walk.

This algorithm for finding a way to destination was developed experimentally, which is an accepted solution, since it is not fully known how exactly ants move nor they are trying to find a optimal path.

3.3 Model Simplifications

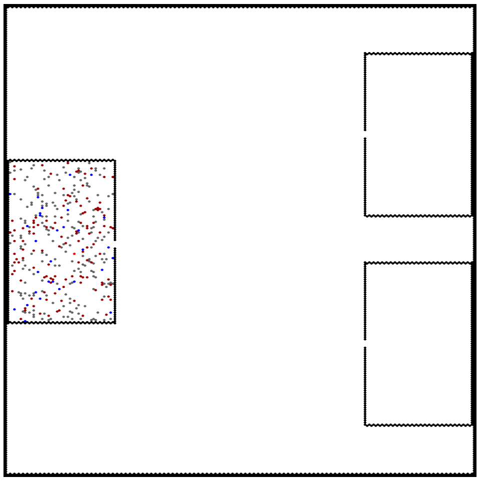
There are some notable simplifications used in this model. First, ants cannot get lost while tandem running or traveling between nests; they always know where the leader ant is and where nests they have been to are. Second, there is no reverse tandem running (where an ant leads another one back to the original nest). Even though it is physically observed in ants and used in a model [4], we did not add this behavior because it was believed to be relatively minor and because of time constraints. These are areas that could be incorporated or improved upon in future work to make this model more ant like.

4. RESULTS

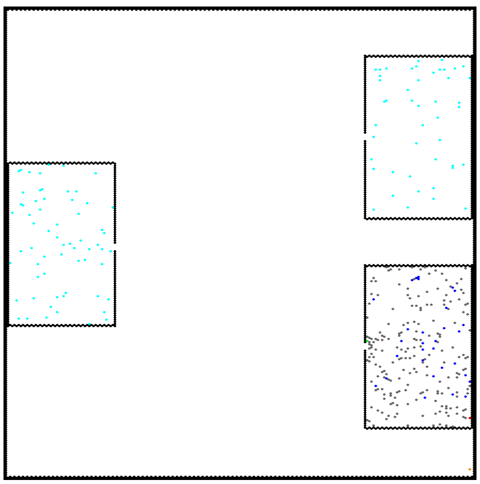
This model was tested on two primary grid and colony sizes, each with a destroyed nest and two other prospective nests (one with twice the quality as the other). The larger of the two has 350 total ants, 110 of which are active ants, a quorum size of 12 ants, and a 220 by 220 grid size. The smaller colony has 150 total ants, 40 of which are active ants and a quorum size of 6 ants with the same grid size. In both of these particular trials, the colonies eventually chose the highest quality nest location. Bigger size of the grids were attempted, but they proved to be infeasible due to the dramatically extended simulation running times. Figure 2 shows a set of still frames from the 350 ant colony size simulation at various points of the decision process These range from the beginning, through tandem walking and transporting, and ending with the vast majority of the ants deciding on the high quality nest (lower-right). The light blue colored ants ending in the original nest (left) or the low quality (upper-right) are recruiters.

4.1 Small Colony

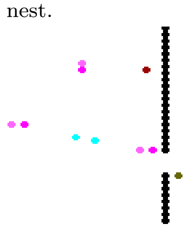
Figure 3 shows some of the results from a small colony simulation in terms of nest population and number of transporters at each timestep. In figure 3a, the total nest population over time that is committed to either the low quality nest and the high quality nest is shown. The high quality nest starts accumulating committed ants before the low quality nest does. Figure 3b shows the number of recruiters that have witnessed a quorum at both of the nests. Figure 3c shows the tandem walking recruiters over time. This figure shows that the low quality nest only have a few tandem walking recruiters and no transporting recruiters. Also, the majority of the recruiting was done via direct transportation.



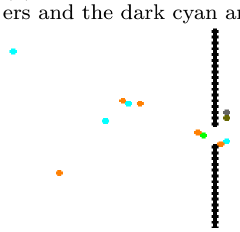
(a) Beginning of the simulation with all ants in the original nest.



(b) End of the simulation where all ants are committed to a new nest.

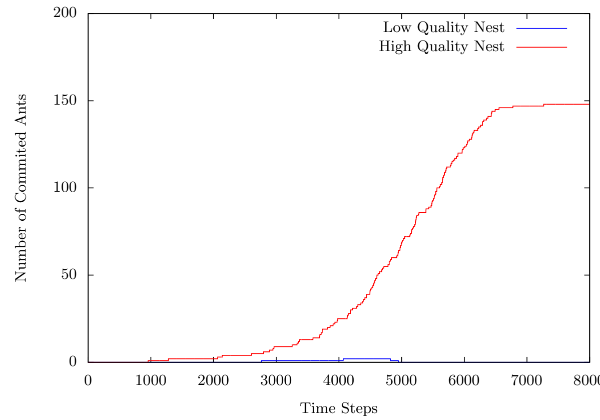


(c) Tandem walking ants. The light cyan ants are the followers and the dark cyan are the leaders in the tandem walk.

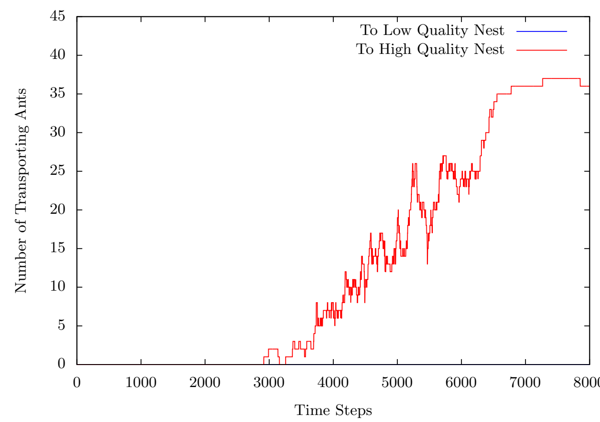


(d) A transporting ant carrying another ant. The orange ants are the transporters. Cyan ants recruiters.

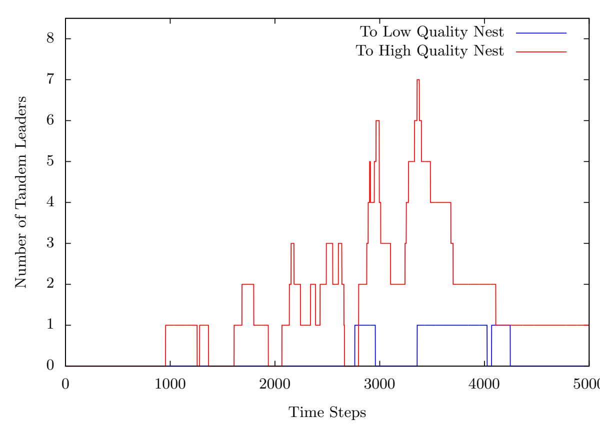
Figure 2: Grid stills from a simulation. The original nest is on the left, the low quality nest is on the upper right, and the low quality nest is on the lower left.



(a) Total number of ants committed to each of the two nests versus time.



(b) Total number of ants transporting to each nest versus time.



(c) Total number of ants tandem walking to each nest versus time.

Figure 3: Graphs showing the number of ants in a colony with 150 total ants, 40 active worker ants, 10 passive ants, 6 ant quorum size, in a 220 by 220 hexagonal grid.

4.2 Large Colony

In contrast to the small colony run, the large colony experienced some splitting between the high and low quality nests. In particular, figure 4a shows there was a short period of time where a portion of the colony chooses or is moved to (in the case of the passive brood) the low quality nest. While the low quality nest is first to have ants being transported, figure 4b, 4c, and 4d shows that eventually the high quality transporters dominate the recruiter population. This is because the more populous recruiters from the high quality nest eventually show the ants that had chosen the low quality nest the better nest. Similar to the smaller colony, most of the recruitment during the course of the trial uses transportation.

5. DISCUSSION

5.1 Parameters & Methods

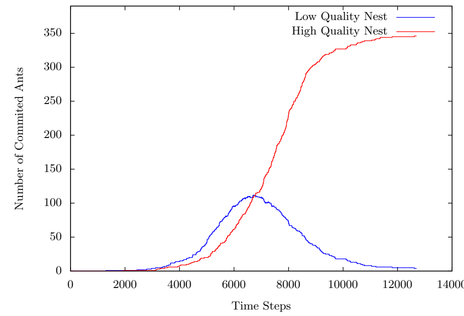
The colony sizes, number active ants, and the grid sizes used in the simulations were all inspired by the models from [3] and [4]. The quorum size was partially determined by the model from [3] and also through manual changes to find interesting behavior. Informally, we found that if the quorum was set to too large of a threshold, the ants would take a very long time before starting transporting other ants. We also tried larger grid sizes with sizes similar to real experiments, but the ants were unlikely to find the new nests. This is probably the result of our simple searching algorithm that may not go far enough in a single direction before turning (or may turn too much when it does). Also, the method probabilistically pushes searching ants back to the main nest after a random number of steps, making long searches unlikely. Adjusting some of the parameters and using better hardware for simulations might be possible solutions to larger grids.

5.2 Results

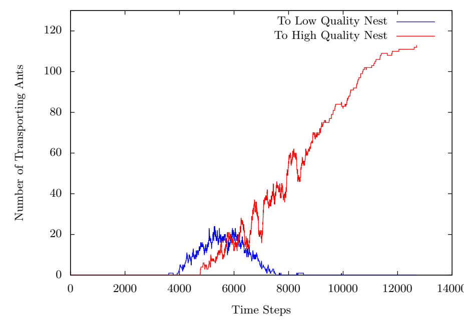
While we have not directly compared it to direct observations of the T. albipennis ants, the agent based model described in this paper appears to mimic the overall behavior of the ants' nest decision making progress. In both the 350 and 150 sized colonies, much of the recruitment is done in the form of transportations, and only a few was done by tandem walking. This is consistent with some of the findings of [4]. The 350 sized colony also exhibited a more complex splitting behavior while the 150 colony did not. This was due in part to chance and in part to the increased number of ants more easily reaching quorum.

5.3 Conclusion

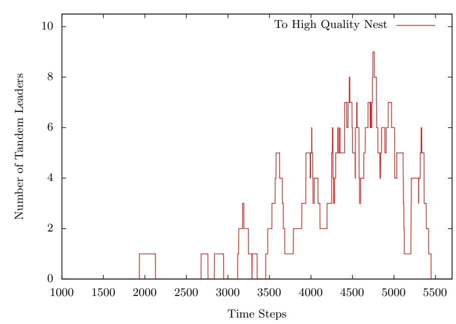
Using simple individual behaviors and without central control, the simulated ants are usually able to find and recruit to nests in such a way as to find the "best" one in our limited number of trials. Even with simple searching, assessing, and recruiting behaviors, the model is robust enough to find and correct colony splits that might happen when portions of the colony choose different nests. For future work, we would like to extend this model to use a more realistic and robust pathing algorithm as well as incorporate some of missing transitions and behaviors from [4] like reverse tandem walks.



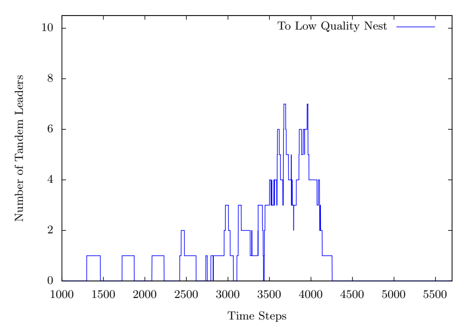
(a) Total number of ants committed to each of the two nests versus time.



(b) Total number of ants transporting to each nest versus time.



(c) Total number of ants tandem walking to the low quality nest versus time.



(d) Total number of ants tandem walking to the high quality nest versus time.

Figure 4: Graphs showing the number of ants in a colony with 350 total ants, 120 active worker ants, 300 passive ants, 12 ant quorum size, in a 220 by 220 hexagonal grid.

6. REFERENCES

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