# Simulation of Nest Assessment Behavior by Ant Scouts

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Abstract. The scouts of *Leptothorax albipennis* colonies find and assess new nest sites, when their current nests become uninhabitable. Observations of these scouts have suggested that they assess, among other things, the integrity of the internal periphery and the size of the potential nest site. The hypothesis that the scouts use a 'Buffon's needle algorithm' to estimate the nest size is supported by experiments. In this paper, we present a behavioral model for the nest assessment of the scouts. This behavior is implemented on an *ant-bot*, a simulated scout model, to study the assessment process. We present the simulation results obtained from this model by systematically varying the behavior and analyzing how well the integrity of the periphery and the size of the nest was evaluated. The results indicate that the accuracy of these two evaluations requires conflicting exploration behaviors, and an optimal behavior requires a compromise in the accuracy of both.

### 1 Introduction

Biological systems are excellent examples of how, seemingly complex, decisions can be obtained through simple behaviors that implement rules of thumb or clever procedures, that have evolved. Modeling the decision making process from direct observations is a common methodology in biology. Although these studies are essential for the understanding of the biological systems, we believe that constructing mechanical models that replicate the results obtained from biological systems, is likely to improve our understanding of these systems. The construction process not only brings to the surface the small design details that may have been skipped during modeling, but it also allows one to vary the parameters of the constructed model to study the other varieties of the model that the evolution had not chosen.

### 2 Nest Assessment in Leptothorax albipennis

Colonies of *Leptothorax albipennis*, a small monomorphic myrmicine ant species, inhabit small flat crevices in rocks. When the current nest becomes uninhabit-

able, the scouts explore the environment to find and assess new nest sites. These ant scouts assess potential nest sites before they attempt to initiate an emigration of the whole colony. In their assessment, the integrity of the inner wall of the potential nest site, and the floor area of the nest site seem to constitute two important criteria. Mallon and Franks[1,2] observed the visits of individual scouts to new sites. They have reported that scouts tend to make more than one visit to a new site before attempting to initiate the emigration of their entire colony. During their visits, the scouts spent a considerable part of their time exploring the internal periphery of the site, while making seemingly random explorations of the central part of the nest, Fig. 1. No significant differences were found between the duration of the first (second) visits to nests of different sizes[2]. It is also observed that in their second visits, the scouts "briefly but significantly slow down" as they cross their first visit trails. Based on these observations and many others, Mallon and Franks[1] suggested that the scouts lay an individual-specific pheromone trail during their first visit, and that they use the intersection frequency of their path with this pheromone trail during their subsequent visits to estimate the floor area of the nest. They pointed out that, this strategy is consistent with the Buffon's needle method, a technique in computational geometry to estimate  $\pi$  empirically, that can be adapted to measure space.



Fig. 1. Two trails of a scout visiting a new nest site as traced by an overhead camera. (a) shows the trail of the first visit, (b) shows the second visit.

They tested this hypothesis by tracing the visits of scouts to different potential nest sites in the laboratory environment. They counted the intersections of traces between the first and subsequent visits separately within the central region and the peripheral region of the new nests. The results obtained were consistent with the Buffon's needle method. Apart from the Buffon's needle method, they have also tested whether the ants use (a) the internal perimeter of the nest, (b) the 'mean, free-path-length algorithm' to assess the size of the nests. However, the experiments showed that (1) scouts were able to choose a standard-size nest over a half-size one with the same internal perimeter and, (2) a partial barrier placed inside a standard-size nest did not affect the assessment of the nest. While exploring a nest, the component of the behavior to check the internal perimeter of a nest might be in conflict with the component of the behavior for the measurement of the nest area. First, the ant will spend less time exploring the central part of the nest decreasing the accuracy of the size assessment. Second, it may be possible that the pheromone trail at the periphery can cause problems for the implementation of 'Buffon's needle algorithm'.

This paper attempts to tackle these issues by constructing a simulation that mimics the environment, the ant and its behavior model for assessing new nests. By varying a parameter of the exploration behavior, the simulation allowed us to study the dynamics of the assessment process for achieving an optimal assessment of a new nest.

In the rest of the paper, we will first present the model for the simulation of the ant and its environment. Second, we will describe the exploration behavior of the ant model proposed for nest assessment. Third, we will describe the experiments carried out and the results obtained. Finally, the results are discussed and future directions for the work are outlined.

# 3 Simulation

We have modified YAKS<sup>1</sup>, a free mobile robot simulator, to study the nest assessment process ant scouts. The simulator is designed to simulate a physical mobile robot, Khepera [3] (K-Team, Switzerland), by sampling the sensory readings from a real robot [4]. Although it is not designed to simulate ants, it is preferred since it models the interactions between the agent (robot) and the environment in a realistic way. The simulation operates in 2-D.

### 3.1 The Ant-bot

The *ant-bot*, sketched in Fig. 2-(a), is created as a model of the scout ants. For this, the original Khepera robot model of the simulator is modified. The ant-bot has four infrared proximity sensors placed in the front to imitate the short-range sensing ability of the ant with its movable antennae, Fig. 2-(b). It is also equipped with a "pheromone nozzle" and a "pheromone detector", both located at the center of the body, the former for laying and the latter for detecting the pheromone in the environment.

### 3.2 The Nests

Three different nest designs, are shown in Fig. 3. These nests are created by walls as a closed rectangular space. Unlike the real nests, used in the experiments of Mallon and Franks [1], the entrances are omitted to remove the possibility of the ant-bot leaving the nest prematurely<sup>2</sup>. The small rectangle shown under the

<sup>&</sup>lt;sup>1</sup> Available at http://www.ida.his.se/ida/~johanc/yaks/

 $<sup>^{2}</sup>$  The scouts seem to spend a certain duration of time during their visits.



Fig. 2. (a) Sketch of the ant-bot. The circle represents the body. The two elongated rectangles placed on the left and right part of the body denote the wheels of the robot. The four small rectangles on the upper part of the figure shows the placement of the infrared proximity sensors. The concentric circles drawn at the center of the robot indicate the pheromone nozzle and detector. (b) Leptothorax albipennis.

nest, marks the position of the entrance. Within the environment the ant-bot is drawn as a circle with a line connecting its right and left and right wheels.

The nest in Fig. 3 (a), shows the standard-size nest used in our experiments. The nest design (b) shows a smaller nest which has half the size of the standard-size nest. The nest shown in (c) is a standard-size nest with a partial barrier placed at the center of the nest. The real ants can detect that nest (b) is too small, yet they are not confused by (c), the standard-size nest with a partial barrier. They respond to (c) as to the standard-size nest (a).



Fig. 3. The three types of nests considered for the experiments: (a) standard-size nest, (b) half-size nest, and (c) standard-size nest with a partial barrier.

### 4 Nest Assessment by the Ant-bot

The ant-bot makes two visits to a new nest. In each visit, it starts its exploration above the entrance at a random alignment. During the first visit, it lays pheromone along its path. During its second visit, instead of laying pheromone, the ant-bot senses the pheromone layed during its first visit, and uses this information to estimate the size of the nest. In both visits, the ant-bot uses the same exploration behavior.

The exploration behavior uses the infrared proximity sensors to drive the ant-bot creating exploration trails that seem to be similar to those observed in ant scouts. The behavior is parametrized in such a way that it can generate a continuum of trails that can range from wall following to random exploration.

#### 4.1 Exploration Behavior

The exploration behavior uses the readings obtained from the four infrared proximity sensors to drive the two motors. The ant-bot is controlled by setting the speed of its left and right wheels  $(m_l \text{ and } m_r)$ , which are calculated as

$$m_l = (1 - |\bar{r}|) * 0.25 - \bar{r}$$
$$m_r = (1 - |\bar{r}|) * 0.25 + \bar{r}.$$

When  $\bar{r} = 0$ , the ant-bot moves forward. It turns left when  $\bar{r} = 1$ , and right when  $\bar{r} = -1$ . Here,  $\bar{r}$  is defined as

$$\bar{r} = \begin{cases} -1 & : & r+n < -1 \\ r+n & : & -1 < r+n < 1 \\ 1 & : & r+n > 1 \end{cases}$$

where n is a random number between -0.4 and 0.4 and r is defined as the value of the 'rotational activation'. The change in r is calculated as

$$\Delta r = -0.9r + 0.3(1 - r)(w_l + 1.5I_4 + 1.2I_3) - 0.3(1 + r)(w_r + 1.5I_1 + 1.2I_2)$$

where  $I_i$  denotes the infrared readings, with a value between 0 (no object) and 1 (very close object), where 1 < i < 4 is the index. Here,  $w_l, w_r$  represent the 'perceived presence' of the wall on the right and left side respectively. The first term on the right of the equation guarantees that when no wall is perceived and the infrared readings are all zero, then any rotational activation will decay to zero in time. The second term raises the rotational activation towards 1 in proportion to the amount of wall perceived on the left side and the infrared readings from the right side. The third term tries to pull down the rotational activation to -1 in a similar way.

The variables,  $w_l$  and  $w_r$ , indicate the presence of the peripheral wall on the left and right side of the ant-bot respectively and the change in them are defined as

$$\Delta w_l = -0.1w_l + \gamma(1 - w_l)I_1 - 0.7w_l(I_2 + I_3)$$
  
$$\Delta w_r = -0.1w_r + \gamma(1 - w_r)I_4 - 0.7w_r(I_2 + I_3).$$

The first term on the left side causes the perceived presence of a wall to decay to zero when no objects are sensed. The second term, increases the perceived presence of the peripheral wall by the activations of infrared sensing on that side. The third term diminishes the perceived presence of any wall if the front sensors become active, to raise the priority of avoidance. The parameter  $\gamma$  controls the perceived presence of the wall. When the parameter  $\gamma = 0$ , both  $w_l$  and  $w_r$  decay to zero, and stay there. For nonzero values of  $\gamma$  the perceived presence of wall becomes stronger.

The exploration behavior defined above can generate exploration patterns ranging from random exploration (that is moving while avoiding the walls), to wall following, by varying  $\gamma$ . When  $\gamma = 0$ , the wall sensing part of of the behavior is removed, and the robot moves in a random way, while avoiding any obstacles on its way. As  $\gamma$  is increased, the wall sensing becomes active creating a attraction towards the wall. As the attraction grows larger, the robot tends to stay closer to the walls and become less likely to move into the central part of the nest. Figure 4 shows three different exploration patterns achieved by different values of  $\gamma$ .



Fig. 4. Different trails can be obtained by varying  $\gamma$ . Three trails from the exploration of a standard-sized nest for 10000 time steps, are shown. These trails are obtained for  $\gamma = 0.0, 0.3, 1.0$ , from left to right. Increasing  $\gamma$  beyond 1 tends to make the attraction towards the wall so strong that it may overcome the obstacle avoidance component of the behavior, causing the ant-bot to crash into the walls. The uncovered periphery is marked as a dark region inside the walls of the nest.

#### 4.2 Evaluating the nest assessment

The assessment of a nest by the ant-bot is evaluated, using two measures: namely, how accurate the floor area is estimated, and how well the integrity of the nest perimeter is checked.

Measuring the size of the nest: The size estimation is done by the ant-bot. The pheromone sensor, denoted as p, returns 0 or 1 reporting the absence or

existence of pheromone under the ant-bot. This reading is processed by leakyintegrator:

$$\dot{\bar{p}} = -0.1\bar{p} + 0.9(1-\bar{p})p$$

that generates a smoother sensory signal. The Buffon's needle algorithm is approximated, by counting the rising edge crossings of this signal with a threshold of 0.5. In the rest of the article, we will use the term 'Buffon count' to denote the number of these crossings counted during the second visit of the ant-bot.

Measuring the periphery coverage: The success of the ant-bot at checking the periphery of the nest, is defined as the area between the inner region covered by the pheromone trail of the ant-bot and the periphery. This evaluation is done by the simulator after the first visit of the ant-bot. The dark regions between ant-bot's trail and the inner periphery, Fig. 4, shows the unchecked periphery for three different explorations.

### 5 Results

The three nest types, shown in Fig. 3 are used in the experiments. For each nest type, the ant-bot made two visits to the nest: the first, lasting for 10000 time steps; the second, lasting for 7500 steps. In each visit, the ant-bot began its exploration in front of the entrance, which is indicated by a small rectangular block below the nest. The initial position of the ant-bot was kept constant except that its initial orientation was varied within  $\mp 15$  degrees of the wall.

We have evaluated the nest size estimates of the ant-bots, and the amount of uncovered periphery while varying  $\gamma$  from 0 to 1. For each value of  $\gamma$ , twenty nest assessments are made by the ant-bot. The median of the Buffon count and the uncovered periphery is plotted with respect to  $\gamma$  and the interquartile range is shown as error bars.

Figure 5-(a) plots the median Buffon count for the different types of nests, with respect to  $\gamma$ . Two points are worth noting. First, even with the Buffon's algorithm in operation at the periphery, where trails are less random, for  $\gamma < 0.3$ , the ant-bot can reliably distinguish between a standard-size and half-size nest. Second, the barrier placed inside a standard-size nest, did not affect the size assessment.

It is interesting to note that, in Fig. 5-(a), at high gamma values the line for the Buffon count in half sized nests dips below the line of the other two larger nests. This occurs because the pheromone trails get "crowded" at the periphery, blending into fewer thicker trails. In the half-sized nest, the ant-bot has the time to make more "rounds" causing more blending than the standard-size nests, hence it makes fewer Buffon counts.

Figure 5-(b) plots the median percentage of covered periphery with respect to  $\gamma$ . It can be seen that, as expected, the amount of covered periphery increases with  $\gamma$ . This suggests that periphery coverage in conflict with the accuracy of the size evaluation.



Fig. 5. Median (a) Buffon count and (b) percentage of covered periphery. The error bars indicate the interquartile range. Note that the percentage of the covered periphery will always be less than 100 since the body of the ant-bot does not touch the periphery.

# 6 Conclusions

We proposed a model of nest assessment in scout ants. The model shows that an exploration behavior that combines obstacle avoidance and wall following, with the addition of a high amount of noise, is sufficient both to generate similar trails to those of the real ants and to enable them assess a nest site accurately. The analysis shows that the exploration behavior has to be tuned to optimize the nest assessment, since the accuracy of nest size measurement, and the completeness of the periphery coverage require conflicting strategies.

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