Simulating Intelligent Emergent Behaviour amongst Termites to Repair Breaches in Nest Walls

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Abstract

Termites exhibit complex and emergent behaviour that is still poorly understood in terms of both causes and mechanisms. We explore emergent cooperative behaviour amongst systems of simulated termites through a microscopic model capable of supporting realistic numbers of individual termites in a nest. We explore possible individual characteristics of a model termite as they might respond to breaches in the nest wall. We report on how a simulated thermal gradient may suffice as a communications mechanisms that enables individual termites to cooperate in repair of a wall breach of their nest or mound on behalf of their macroscopic community. We review how intelligent agent-based models could explain some observed termite collective behaviours.

Keywords: termites; Agent Based Models; emergent behaviour; autonomous systems.

1 Introduction

Termites have long been studied extensively and much is known about their classification, physiology and reproductive systems – see [1] for a good overview. There is also significant work on the DNA and gene sequencing of termites within and across distinct colonies [2]. Interesting insights into the construction of termite mounds [3] have led to speculation that buildings could be constructed in a similar fashion leading to dramatic reductions in the energy required for heating or cooling [4].

However, far less is known about individual termite behaviour. Termite colonies are highly complex systems with emergent properties and behaviours that are not obvious from the behaviours of individuals [5]. Detailed field observations [6] indicate that termites cooperate (in repairing breaches, for example) with no obvious communication as they are blind and appear not to produce pheromones in the way that ants do.

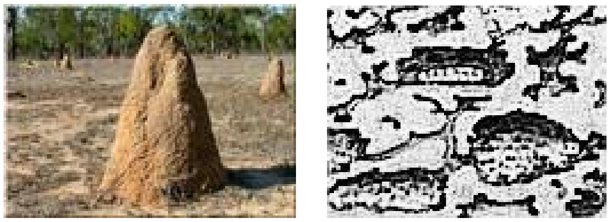

Figure 1: A typical termite mound (left) and a cross-section of the tunnels and passageways taken through it (right).

Agent Based Models (ABMs) [7] have been used to model a range of topics from trading [8] to battlefields [9]. Several such models have been constructed to study termites but these study only a particular behaviour involving a very limited number of agents – for example activations of resting termites [10] and defense of a colony [11]. A sophisticated model of a termite colony may provide further insights into their cooperative behaviour. Figure 1 shows a typical termite mound structure and a cross-section through it. Our model is an attempt to capture some of the termite movement behaviour through a simulated structure like that shown.

In this article we present the early stages of what we hope will become a more comprehensive model to explore termite behaviour. It is important to construct and analyse the model in stages to provide a firm foundation for future work. This model is based on extensive previous work [12] with an abstract predator-prey model which included included extensive fine tuning of the model [13] to enable the creation and maintenance of large numbers of agents (up to a million in some cases). These large numbers in turn enable the emergence of behaviours not possible in smaller, simpler models.

We focus in this article on possible mechanisms for termites to detect and respond to a wall breach in their nest or mound. This behaviour is well observed and documented but it is still unknown exactly how individual termites know to respond to the breach and how they make their way to it and participate in collective rebuilding. We start from simple statistically localised termite motion and consider how a global mechanisms might enable termites to respond and move towards a specific goal - such as the location of a wall breach.

A brief overview of the model is provided in section 2. Various techniques for implementing termite movement are discussed in section 3 and we present some results in simulating termite motion towards wall breaches in section 4. We offer some tentative conclusions and and a discussion of future work areas in section 5.

2 The Termite Model

The termite model is based on our previous predator-prey model [12] which in turn is based on traditional models such as [14, 15]. The two main elements of the model are firstly the agents and secondly the map in which they are located and where they interact and cooperate.

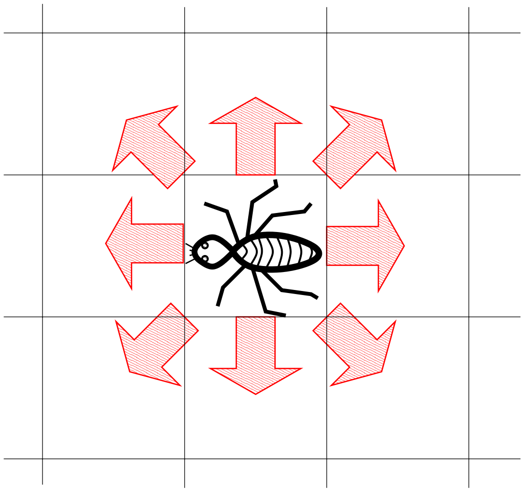

Figure 2: An individual termite can move according to its internal micro program to any adjacent open site - not part of the nest wall.

Our past experience has been that it is easier to simulate a large number of spatial agents if the space is discretised and this individuals can have clear micro-programmable notions for moving to a nearby location and can detect what is in their immediate vicinity. At a programming list this allows a spatial grid to help organise locations and gives a data structure that is faster to arrive at individual agent decisions that traversing arbitrary lists would be. Figure 2 indicates an individual termite, modelled as occupying a square cell in a grid that has occupiable sites and wall masked sites according to the model map.

The present map consists of a two-dimensional grid of cells with termites located in the cells. This principle could be extended to a three-dimensional configuration in future work.

The map consists of two areas: the tunnels and the restricted area. Termites may only be located in, and move through, the tunnels and are never allowed into the restricted area. The model reads a BMP file directly, thus new maps can readily be created and used in the model. Three different maps were used for the experiments discussed here: a random map, a disc-shaped map and a torus-shaped map – see Figures 3, 4 and 5.

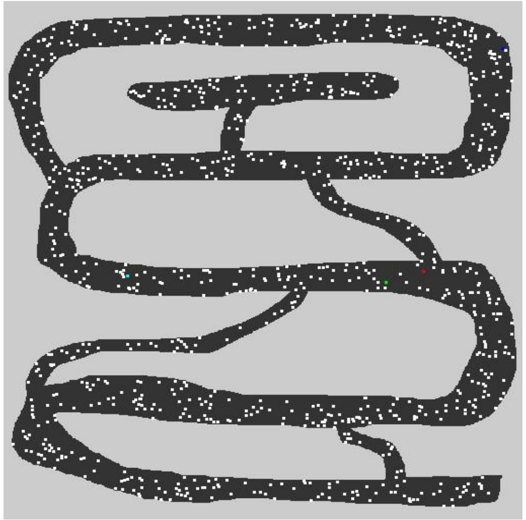

Figure 3: 1000 artificial termites on a randomly created map

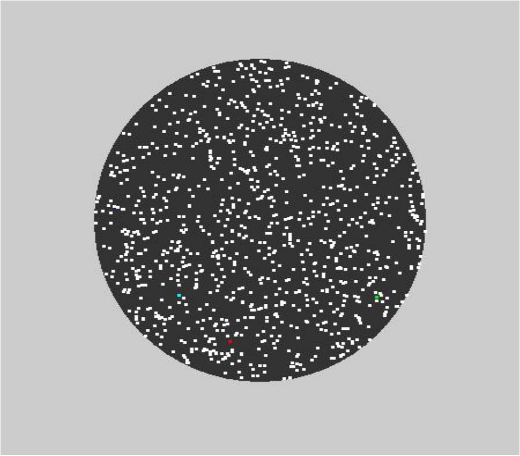

Figure 4: 1000 artificial termites on a disc-shaped map

A simulation "run" is initialised by scattering a number of agents (artificial termites) randomly and evenly throughout the tunnels of the map. The actual number of agents is selected on start up and a typical simulation will contain between 1,000 and 10,000 termites. It is possible to considerably increase this number but this will eventually overcrowd the available tunnels.

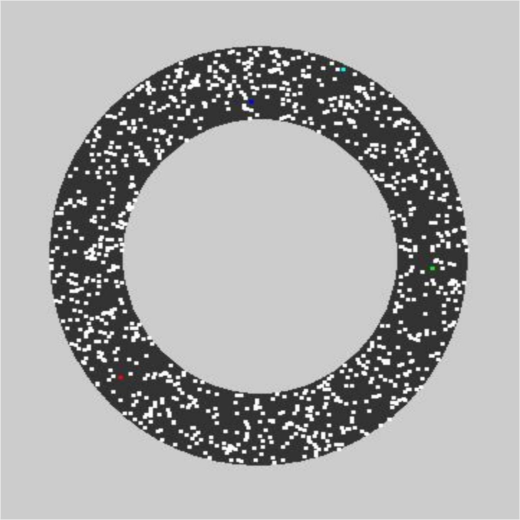

Figure 5: 1000 artificial termites on a torus-shaped map

Each termite has a set of microscopic rules that govern its behaviour. At each discrete time step of the model every agent is given an opportunity to execute its preferred behaviour. A multi-phase algorithm is used to ensure reproducibility and resolve interacting conflicts between agents' desired actions. At this early stage of the model termites have a tiny rule set as follows:

1. if a temperature change is detected – move along the temperature gradient
2. if adjacent to a breach – repair the breach
3. move randomly

All termites always execute one rule in each time step. The rules are consulted in the given order and the termite always executes the first rule in its list for which the conditions are satisfied. If the conditions for a rule can not be satisfied (for example, a breach can not be repaired unless a breach exists) the agent must try the next rule in its priority list. The order of the rules can thus have an important effect on termite behaviour. For instance, if the rule "move randomly" was listed as the first rule, then all termites would always move randomly and no other actions would take place.

The rule set is designed to be easily expanded when required and, in time, could include additional rules covering situations such as detection and repulsion of intruders, feeding and care of the queen, food production and distribution and so on. Termites could also be divided into castes – such as soldiers and workers – and each caste could have a different rule set. Future work could include breeding new workers in which the rule set could evolve over generations.

3 Termite Movement

In this section we describe mechanisms for making the individual termites move in an appropriate manner. There are three types of termite movement we simulate:

- move along a temperature gradient
- move randomly – but in straight line segments
- move randomly – completely random

A termite uses the first type of movement when a breach has occurred. By moving along the temperature gradient the termite will eventually move to the breach. The other types of movement are used when moving randomly: with straight line segments, the termite keeps moving in the same direction until the path is blocked when it randomly selects a new direction; with completely random movement, the termite selects a random direction every time step. Completely random movement usually ensures that the average termite will not move far away from its starting position whereas, with straight line movement, individual termites have been observed traversing the entire colony.

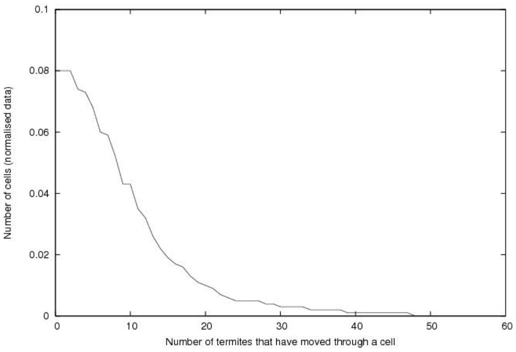

Figure 6: Cell visitation histogram for 1000 termites over 1000 steps moving in straight line segments on a random map with maximum stacking of 10.

Figures 6, 7 and 8 show cell occupation rates for 1000 termites moving randomly – but in straight line segments – on a random map, a disc-shaped map and a torus-shaped map - as typified by the illustrations in Figures 3, 4 and 5, respectively. The movement in straight line segments ensures that termites move over a large part of the map area. Due to the random nature of the random map, there are some tunnels (or some of the cells of a tunnel) which are less likely to be used and only 1 or 2 termites have moved through those cells. In the more regular maps, there are considerably fewer such cells.

Figures 9, 10 and 11 show cell occupation rates for 1000 termites moving completely randomly on a random map, a

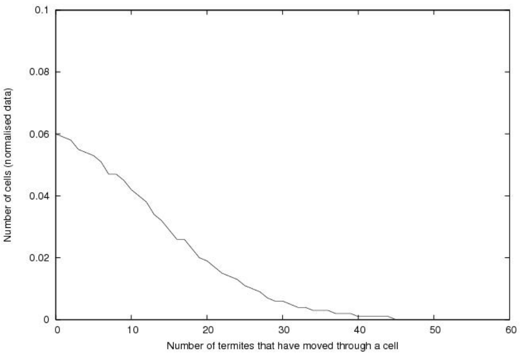

Figure 7: Cell visitation histogram for 1000 termites over 1000 steps moving in straight line segments on a disc-shaped map with maximum stacking of 10.

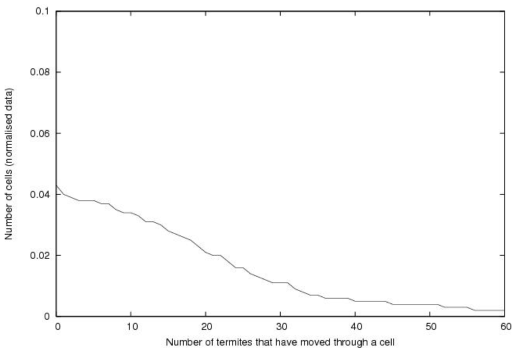

Figure 8: Cell visitation histogram 1000 termites over 1000 steps moving in straight line segments on a torus-shaped map with maximum stacking of 10.

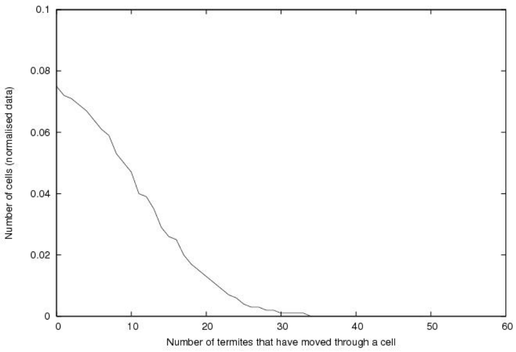

Figure 9: 1000 termites over 1000 steps moving completely randomly on a random map with maximum stacking of 10.

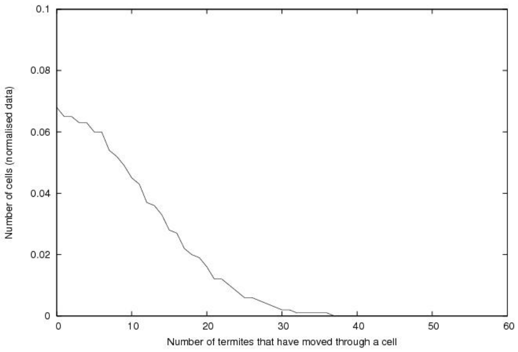

Figure 10: 1000 termites over 1000 steps moving completely randomly on a disc-shaped map with maximum stacking of 10.

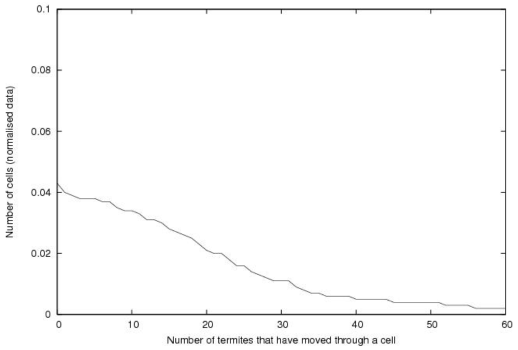

Figure 11: 1000 termites over 1000 steps moving completely randomly on a torus-shaped map with maximum stacking of 10.

disc-shaped map and a torus-shaped map. Although the differences between the maps still exist, in all cases the number of cells with low numbers of termites has decreased. This is due to the fact that the completely random movement tends to keep termites in the vicinity of the initial location.

Agents in the model can be allowed to “stack” (several occupy the same cell). This not only allows more termites to fit into the same area but also appears to match the behaviour of real termites that have been observed to literally climb over one another when required [6]. In a modelling sense this aspect is effectively a coarse-graining [16] of sub-microscopic spatial cells which would have strictly at most one termite agent occupying them at once. This is a widely accepted modelling technique, especially for stochastic models, although as Nicolis *et al.* report the exact nature of the spatial cell sizes and effective cutoffs is still an open research question. Each of our model cells is thus a spatial integration of possible sub-cells. The model has a maximum stack limit and this is usually set to 10. Thus 10 termites could occupy the same cell in a tunnel but in practice it is rare to find more than 2 or 3 stacked together. The stack limit does have an effect if the number of termites is increased (without increasing the corresponding tunnel area).

The effects of stacking can be seen in Figures 12 and 13. Figure 12 shows the effect of imposing a stack limit of 1 and should be compared with the more generous stack limit of 10 shown in Figure 6. Figure 13 shows the effect of the reduced stack limit of 1 when far more termites are present – 5000 instead of the usual 1000. In this case termites are forced to use hitherto unused tunnels and thus the number of cells with low occupation (over 1000 steps) is greatly reduced with a corresponding increase in the number of cells with higher occupation over time.

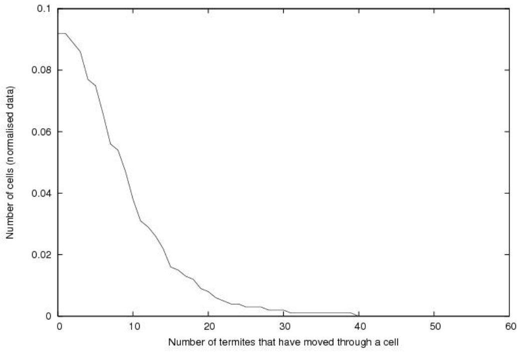

Figure 12: 1000 termites over 1000 steps moving in straight line segments on a random map with maximum stacking of 1.

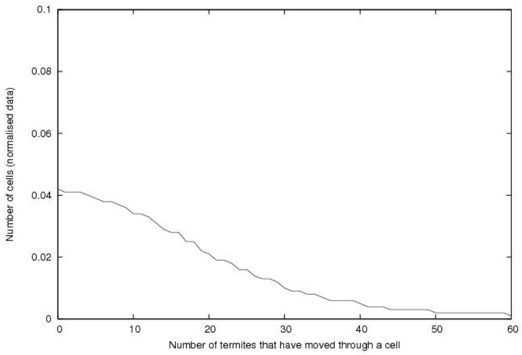

Figure 13: 5000 termites over 1000 steps moving in straight line segments on a random map with maximum stacking of 1.

These experiments show that we have a "well behaved" spatial agent with known base-level spatial and exploratory behaviour. The individual termite agents exhibit correct spatial diffusion behaviour when they follow their individual internal micro-behaviours. We could model the pathways explored by individual termites using a traffic model such as an Asymmetric Exclusion Process [17]. This can be done by modelling termites as a "single channel" in a transport system [18]. For the purposes of the present paper however we consider the effect of directed diffusion [19] and seek a means for termites to deviate from mean-field behaviour. In the next section we explore how individual termites might seek out a global spatial goal such as a wall-breach.

4 Simulated Breaches

Termites are known to react vigorously when a breach is made in the mound and workers rush to the breach to seal it off. The model simulates the effects of a breach by creating a temperature gradient from the breach into the tunnels of the colony. If agents detect a temperature gradient they follow it to the breach and can then attempt to repair the breach. During this period, random movement ceases for most termites and the patterns of tunnel occupation change.

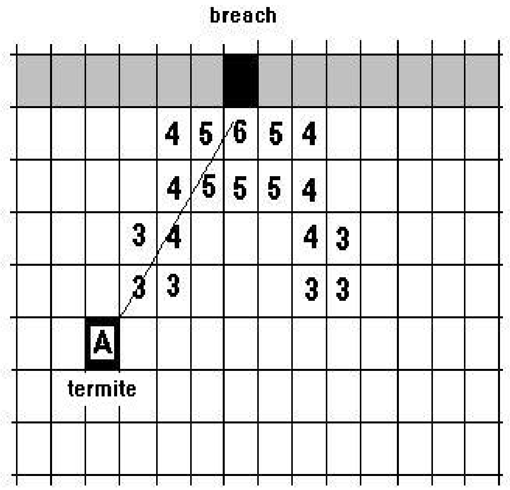

Figure 14: A breach in the tunnel wall causes a temperature change to spread into the tunnel. Each cell includes a current temperature which is incremented each time step and spreads outward to adjacent cells. Not all cell temperatures are shown. Termite A moves up the temperature gradient to get to the breach.

Figure 14 shows how the environment map might be modified to introduce a wall breach and a consequent thermal gradient for the termite to follow. Our assumption here is that the termite nest is chimney-cooled, as described in the literature, and that therefore it is **warmer** air from the outside the termites sense propagating from the breach. Figure 15 indicates how the microscopic probabilities of movement direction choice might be modified (for an individual termite at a specific location) in the map grid.

Figure 16 shows a contrast to the behaviour of figure 6 whereby the cell visitation histogram has tightened considerably with much less of a long tail. This is characterised by the half-width at half maximum (HWHM) of the one-sided distribution and summarised n table 1 below.

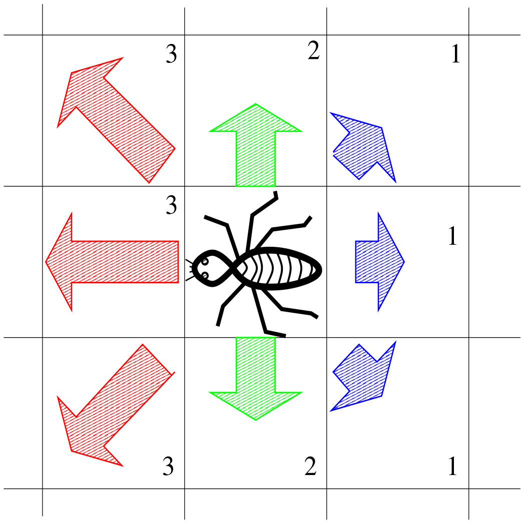

Figure 15: A termite can be "micro-programmed" to follow the perceived thermal gradient. This will modify its random movement in favour of directed diffusion up the thermal gradient.

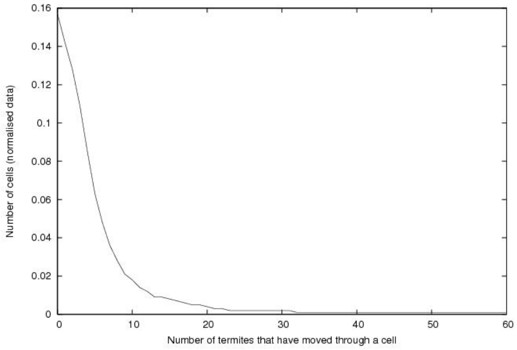

Figure 16: 1000 termites over 1000 steps moving in straight line segments on a random map. During this period there is a breach in the wall of a tunnel.

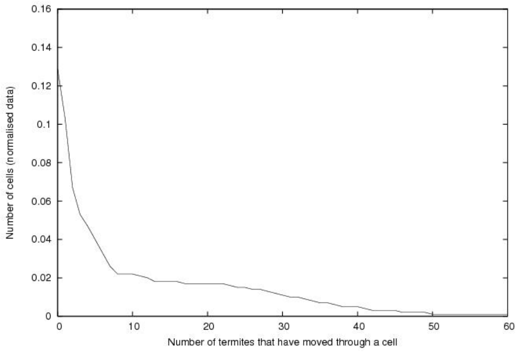

Figure 17: 1000 termites over 1000 steps moving in straight line segments on a disc-shaped map. During this period there is a breach in the wall of a tunnel.

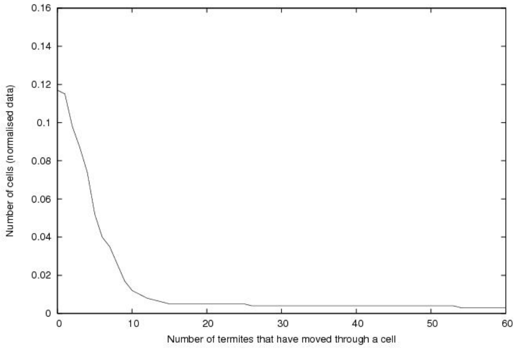

Figure 18: 1000 termites over 1000 steps moving in straight line segments on a torus-shaped map. During this period there is a breach in the wall of a tunnel.

Figure 17 shows a departure from the behaviour shown in figure 7 again showing a tightening of the distribution of termite visitations in cells. This data is no longer a simple one-sided normal distribution and appears to be bimodal, exhibiting a second peak at around 22 termites.

Figure 18 shows a departure from the behaviour shown in figure 8 and also appears to have a bimodal pattern with a secondary peak at around 22 termites.

The general effect of the wall breach appears to be as hoped for. The temperature gradient "signal" has summoned termites towards a specific spatial goal and the histograms show definite departures from the random motion behaviours. When a breach is flagged, termites will visit the less frequented corners of the nest even less often and the traffic patterns are correspondingly changed. Table 1 summarises the half-width at half-maximum values for the three spatial patterns and the three movement models. Generally the random pattern and disk are broadly similar for all models showing that the straight lines available (on average) in the two spatial patterns are not significantly different. Whereas for the torus pattern there is a different mix of length and hence pathways available for the termite agents to follow.

The third column shows the dramatic effect of the breach and the summoning of termites towards it. This drastically tightens the cell visitation histogram and shows termites spending much more time moving to the breach instead of visiting all main parts of the nest.

5 Summary and Future work

We have presented a preliminary agent-based model for investigating collective termite behaviours. Individual termites are spatially located agents in a simulated physical environ-

Pattern / Movement	Straight Line	Completely Random	Straight Line with Breach
Random Paths	10	12	4
Disk Pattern	14	12	3
Torus Pattern	23	21	4

Table 1: Half-Width at Half-Maximum for Cell Visitation Histograms under various termite agent movement models. Data based on 1000 Termites over 1000 steps, and estimated ±1 termite.

ment – in this paper we focus on a termite nest or mound. We have formulated individual termite agents with very simple and localised microscopic behaviours and pose the question as to how they can be made to respond to a global event such as a wall breach in the nest. We have shown that a temperature gradient – implemented in a relatively simple manner, may be sufficient for individual termites to respond and to find their way to the breach. This is one possible global communications mechanism although several others have been suggested in the termite literature.

The one-sided normal distributions of the randomly moving termite agents show that although termites would be statistically inclined to move everywhere, the geometry of the nest - whatever it is - means that some parts of the system get visited considerably more than others. The main thoroughfares in the random nest pattern, or the straight line walkway paths available in the disk and torus get considerably more traffic.

The deviation from the one-sided normals that arise from the breach seeking behaviour indicates that, statistically, termites are spending even less time exploring the nest structure and are indeed seeking out a globally indicate d spatial goal.

We expect this model can be expanded in a number of ways, both in terms of more realistic three dimensional environments such as the nest - but also in terms of different classes or castes of termite that carry out microscopically different tasks within their community.

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