Computational Science Technical Note **CSTN-085**

Cross-Caste Communication in a Multi-Agent Predator-Prey Model

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2011

Communication amongst multi-agents in a system gives rise to complex emergent phenomena that remain poorly understood in terms of the underpinning mechanism. We explore communications mechanisms between multi-agents in a many-agent spatial predator prey model. We focus on solider-worker scenarios in a swarm-like model where swarm collectives compete for resources and can gain an advantage by trading off numbers of unproductive soldiers against numbers of defenseless but productive workers. We show how even relatively simple cross-caste communications allows a particular collective to maintain a smaller and therefore less expensive army by making it more mobile and responsive to enemy incursions. We discuss possible communications mechanisms and issues for real collective communities such as termites or bacterial colonies where workers might summon soldiers to where the battlefronts form.

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BiBTeX reference:

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@INPROCEEDINGS{CSTN-085,
        author = {C. J. Scogings and K. A. Hawick},
        title = {Cross-Caste Communication in a Multi-Agent Predator-Prey Model},
        booktitle = {Proc. Int. Conf. on Artificial Life and Applications (AIA 2011)},
        year = {2011},
        pages = {163-170},
        address = {Innsbruck, Austria},
        month = {14-16 February},
        publisher = {IASTED},
        doi = {10.2316/P.2011.717-061},
        keywords = {multi-agent systems; animat agents; communicating agents; caste divisions},
        owner = {kahawick},
        timestamp = {2011.06.25}
}
```


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Technical Report CSTN-085

Cross-Caste Communication in a Multi-Agent Predator-Prey Model

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Abstract

Communication amongst multi-agents in a system gives rise to complex emergent phenomena that remain poorly understood in terms of the underpinning mechanism. We explore communications mechanisms between multi-agents in a many-agent spatial predator prey model. We focus on solider-worker scenarios in a community-like model where collectives compete for resources and can gain an advantage by trading off numbers of unproductive soldiers against numbers of defenseless but productive workers. We show how even relatively simple cross-caste communications allows a particular collective to maintain a smaller and therefore less expensive army by making it more mobile and responsive to enemy incursions. We discuss possible communications mechanisms and issues for real collective communities such as termites or bacterial colonies where workers might summon soldiers to where the battlefronts form.

Keywords: multi-agent systems; animat agents; communicating agents; caste divisions.

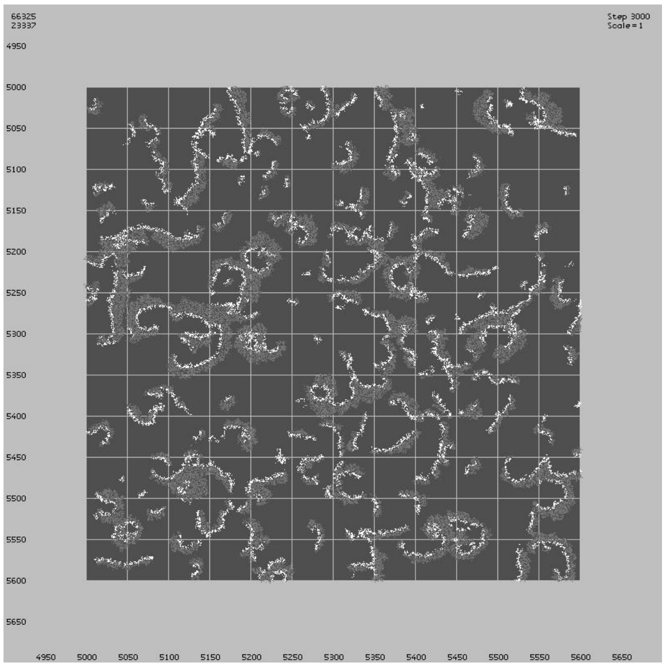

Figure 1: The situation at step 3000 of a typical run showing animats on a square grassed area. Predators are white and prey are light gray. Various macro-clusters, including spiral formations, have emerged.

1 Introduction

Communication amongst spatial multi-agents makes possible a number of complex and emergent behaviours. The mechanisms for communications between bacteria [1, 2] and termites [3] and other biological systems are still poorly understood, but it is possible to hypothesise a mechanism and explore its possible consequences in a multi-agent model system [4]. Understanding how communication behaviours arise amongst different castes of worker in colonies is a particularly long standing problem [5].

A body of work exists on communicating agents in predator-prey models. This includes predators communicating with each other while hunting [6] and prey sending warning signals to other prey [7]. These are examples of predator-prey models that concentrate on the *evolution* of communication and language. In this regard they are typical of Artificial Life simulation models such as [8–10]. All these models concentrate almost exclusively on the evolution of "digital organisms" and the corresponding emergent macro-behaviours and they are less concerned with the microscopic details of the lives of individual "animats" [11] or spatially located multi-agents.

Our predator-prey model [12] has been refined over a period of several years of experimentation. Instead of noting evolutionary behaviour (which is often difficult to measure) we have concentrated on making small, well-defined adjustments to the model and then analysing the emergent new macro-behaviours. In particular we have documented rich structured emergent clusters such as the defensive spirals and other features discussed in [13]. Typical complex formations, including spirals, can be seen in Figure 1 where the flat world of multi-agents has self organised from an initially random uniform mix to a highly structured set of interleaving communities.

Unlike other Artificial Life models, we have concentrated on an analysis of the effects of "higher-order" social interactions such as altruistic behaviour, trading and species segregation. Our predator-prey model has provided a useful platform that has allowed us to make relatively simple modifications to predator behaviours which give rise to amplified responses in the animat population as a whole and which we can study numerically through the use of simulations of multiple independent runs of model systems comprising large numbers of individual animats.

In previous work [14] we explored the effect of soldier-worker specialisation in the predator population. Artificial Life models of such communties tend to restrict themselves to general worker behaviour (for example, see [15]) and do not cover the different roles played by the distinct castes within the community. We found that soldier-worker cooperation was limited by the absence of communication between animats within our model. This article reports on how the inclusion of a simple signalling system enhances animat efficiency.

A brief overview of the predator-prey model is provided in section 2. Section 3 covers the modifications to the predators in order to introduce two distinct castes with the ability to signal one another. Then follow experiments on systems with: randomly scattered starting positions (section 4); territorial-based starting positions (section 5); signals used by one side only (section 6); and conflict between unequally matched forces (section 7). A summary and conclusions are provided in section 8.

2 The Animat Model

Animat models such as ours use spatially located multi-agents that interact with one another in a simulated environment. Typically such models use short range local interactions but in this paper we explore the addition of longer range "signalling" communication mechanisms between animats. Our previously established animat model is based on the notion of two species of software agents that coexist on a spatial landscape. Our present system is a flat land in two dimensions although the concepts in principle extend to a three dimensional configuration. Each animat has a set of microscopic rules that govern its behaviour. At each discrete time step of the model every animat is given an opportunity to execute its preferred behaviour. A multi-phase algorithm is used to ensure reproducibility and resolve interacting conflicts between animats' desired actions. Animats are initially distributed in a random pattern, and as we have reported in previous work [16], the statistical behavioural properties of the collective of animats as a whole is remarkably insensitive to the individual starting conditions, providing sufficient quantities of animats survive the well known boom-bust population cycles that occur in all predator-prey systems [17].

Our animats typically live for a few tens of time steps, during which they can eat; reproduce; flee a predator; seek a potential mate; move randomly or do nothing. Predators and prey have almost the same set of basis rules, but differ in what they will eat or seek/avoid. Predators eat prey and will have a rule to seek prey. Prey will eat static "grass" from the environment and will have a rule to flee from predators. We have experimented extensively with different combinations of these individual rules. All animats always execute one of their rules each time step, but they might try them in a different priority list. Also some rules might fail – for example "eat prey" will fail if there is no adjacent prey animat – and the animat in such a circumstance must try the next rule in its priority list. The rule sets used for the experiments described here are listed in Table 1.

Table 1: Animat micro behaviour rules.

Rules for predator animats:	Rules for prey animats:
1. breed if health $> 50\%$ and mate adjacent	1. breed if health $> 50\%$ and mate adjacent
2. eat prey if health $< 50\%$ and prey adjacent	2. eat grass if health $< 50\%$
3. seek mate if health $> 50\%$	3. seek mate if health $> 50\%$
4. seek prey if health $< 50\%$	4. move away from adjacent predator
5. randomly move to any adjacent position	5. randomly move to any adjacent position

These stochastic rules effectively govern the rates at which the motion, reproduction and interaction processes occur in the system. Each animat has the following state variables: species (predator or prey); location (xy-coordinates); current age; current health; and a set of rules. The model also requires the following global constants for each species: maximum age; maximum health and vision range (used to locate other animats). These are integer values and the model is relatively insensitive to the exact values used for these. When an animat is created ("born") its current age is initialised to zero and is then incremented every time step. If the maximum age is reached the animat "dies of old age" and is removed. Similarly, an animat starts with its current health initialised to the average of its parents'. Each time step the current health is reduced and if it reaches zero the animat "starves to death". Current health can be increased by eating but can never be greater than the maximum health for that species. Early versions of the model started a new animat with full health but this led to predator populations surving for long periods without prey as each new generation had enough health available to produce the next generation.

Most rules carry conditions usually relating to location or current health. The rules are consulted in an order of priority and the animat always executes the first rule in its list for which the conditions are satisfied. The "Breed Rule" regulates the production of new animats and when an animat is "born" it inherits the rules of its parents. The "Breed Rule" does not always succeed. If the necessary conditions (listed above) are satisfied, there is still only a random chance that a new animat will be produced. This chance is known as the "birth rate" and is an abstraction of the cumulative effect of several unknown factors including birthing difficulties, availability of suitable shelter, etc. It would be extremely difficult to simulate these factors separately so it is convenient to substitute one value which produces the desired effect in the model. Normally the birth rate for predators is set to 15% and the birth rate for prey is set to 40% but these can be modified to produce different effects in the simulation.

3 Animat Castes and Introducing Signals

In our previously published experiments, all animats (of one species) carried the same rule set and executed the same rules. In a previous publication [14] we experimented for the first time with animats that have specialized tasks. The predators were divided into two castes – the "workers" and the "soldiers". This idea is loosely based on termite colonies [18] but is at a far more abstract level.

Predators are divided into two distinct "tribes" that compete for resources (prey). Predators are usually workers (which are standard predator animats as described in section 2) but there is a chance that a new predator may be created as a soldier instead of a worker. The chance of this happening is controlled by parameters that can be set to different values for each experiment. During these experiments the chance of creating a soldier was set to 15%. A soldier is a predator with a very specific role. It exists solely to destroy animats of the opposing tribe. When a soldier is adjacent to one (or more) enemy workers, one of the workers is destroyed. If the soldier is adjacent to an enemy soldier there is a chance that the enemy soldier will be destroyed. This chance differs for each tribe and is controlled by parameters set for each experiment. Thus each predator tribe is initialised with two control variables as follows: **soldier-production**: chance that a soldier will be created (usually 15%); **soldier-effectiveness**: chance that a soldier will destroy an adjacent enemy soldier (usually 50%).

Soldiers do not eat but still require food in the usual way. The workers are given the additional task of providing food for the soldiers. When a worker is adjacent to a soldier of the same tribe, the worker will share health points with the soldier. During this exchange of health points, the health of the worker will decrease and the health of the soldier will increase. In this way, a community is penalised for maintaining too many soldiers. It is important to note that the definitions of "tribe", "worker" and "soldier" apply only to the predator population. In previous experiments [19] we found it useful to measure the behaviour of the predators as the "higher life form" and to use the prey merely as a food resource. Thus the rules and behaviour of prey remain unchanged during these experiments.

Creating, maintaining and operating soldiers is complicated and it is difficult to find the most effective way in which to do this. Previous work [14] identified that a form of communication may assist in making soldiers more efficient. This article introduces cross-caste signals and investigates whether such signals increase soldier effectiveness. The model has been modified in the following ways: when a worker is attacked by an enemy soldier it broadcasts a signal to all friendly soldiers. The soldiers respond by moving towards the signal. If a soldier receives multiple signals, it will move towards the nearest signal. This system of signals is depicted in Figure 2 and the augmented rule set for soldiers to respond to signals from workers can be found in Table **??**. In all other respects (e.g. food requirements), soldiers continue to behave as explained above.

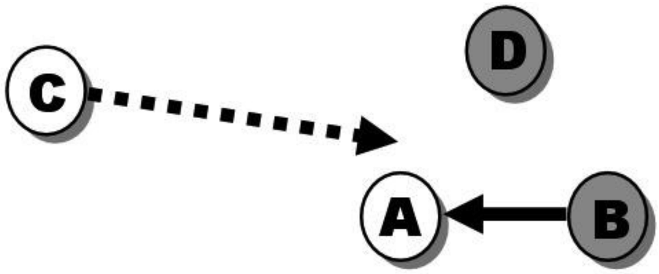

Figure 2: A worker (A) is attacked by an enemy soldier (B). Before the worker is destroyed it emits a signal that is picked up by a friendly soldier (C) that responds by moving towards the source of the signal. When (C) arrives it will destroy nearby enemy worker (D) which will, in turn, emit a signal that will attract yet more soldiers.

Table 2: Augmented Soldier rule set.

1. attack enemy soldier if adjacent
2. destroy enemy worker if adjacent
3. move towards the nearest signal (if any)
4. randomly move to adjacent position

4 Experiment 1 – Random Start with Signals

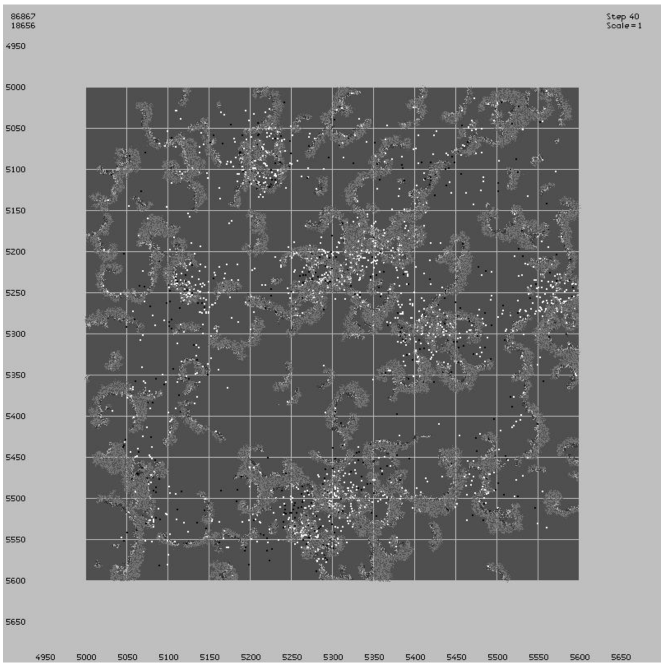

Figure 3: Step 40 of a run in which predators were allocated randomly (but evenly) to either Tribe 1 (black soldiers and dark grey workers) or Tribe 2 (white soldiers with light grey workers).

Predators were allocated to tribes randomly and evenly across the map, producing a "salt and pepper" effect. The soldiers of both tribes had identical capability in that all soldiers had a 50% chance of destroying an adjacent enemy soldier.

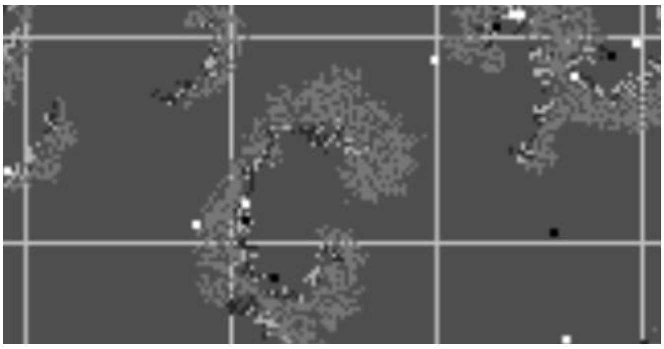

Figure 4: Detail of Figure 3 showing workers of both Tribe 1 and Tribe 2 mixed randomly together and feeding off the same cluster of prey. Soldiers of both Tribe 1 (black) and Tribe 2 (white) are visible as larger squares. The behaviour and distribution of prey remains unchanged.

The behaviour and distribution of prey (food resources) remained unaffected by the competing predator tribes. Both tribes employed signalling as described in section 3 above. Figures 3 and 4 depict a typical situation in the early stages of one such experiment.

The results of this experiment show that signals have a definite effect on tribal conflict in that soldiers of both tribes are rapidly drawn into major battles at various sites across the map. Eventually one tribe dominates but chance (random number seed) dictates which tribe will dominate.

5 Experiment 2 – Fixed Territory with Signals

In this experiment, the predators were again divided into two tribes. However the animats were not allocated to tribes randomly, but rather by location. Thus Tribe 1 consisted of all predators with an x-coordinate of 5306 or less and Tribe 2 consisted of all predators with an x-coordinate greater than 5306 (see Figures 5 and 6).

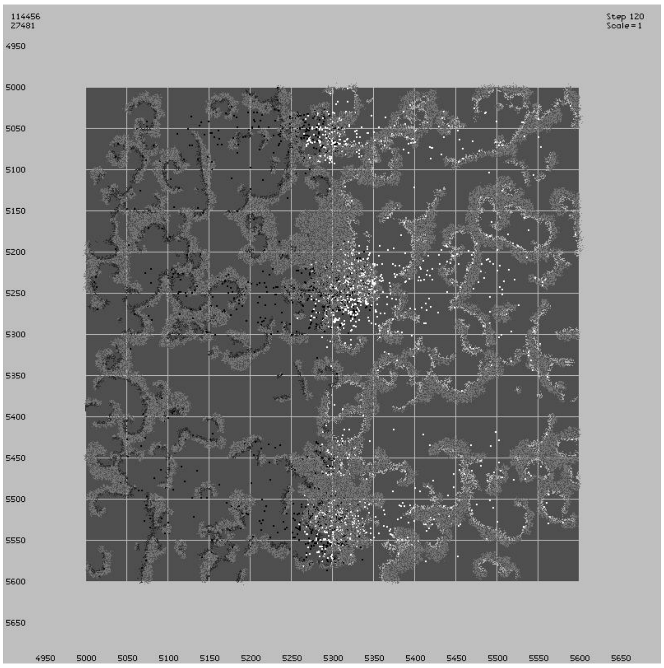

Figure 5: The situation at step 120 of a run in which two tribes of competing predators are both using signalling. The predators were assigned to tribes based on their location. The soldiers of both sides (black for Tribe 1 and white for Tribe 2) are streaming into distinct "battle sites".

This division ensured that not only did the two tribes have almost exactly the same number of animats, but also that each tribe occupied a fixed region with a definite "front line" between them. Both tribes employed signalling and they retained identical capabilities in that the soldiers of both tribes had a 50% chance of destroying an adjacent enemy soldier.

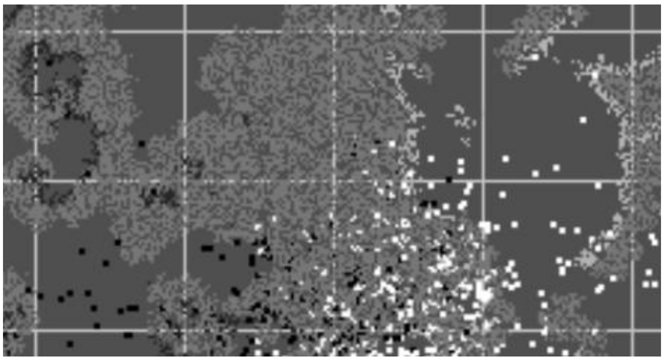

Figure 6: Detailed blow-up of Figure 5 showing that workers of both tribes were destroyed enabling prey to form a larger cluster than usual. Workers of Tribe 2 (light grey) have moved back to feed off the large cluster of prey whereas workers of Tribe 1 have not reformed along their edge of the prey cluster.

The territorial nature of the starting positions ensured that the battle sites in this experiment were even more distinct than those in section 4. The number of soldiers in close proximity at these sites also caused an unexpected emergent effect in that predator workers were destroyed leading to an increase in prey in certain areas. It was noted that as the soldiers of one tribe were driven back from these areas, the workers of the victorious tribe would colonise the edges of these enlarged clusters of prey. These workers were then nearby the victorious soldiers and able to easily provide them with food, thus ensuring further success in future battles. It was this factor that ensured that Tribe 2 dominated every simulation in this experiment (even with different random number seeds) unlike the situation in experiment 1 which was chance-dependent. Due to the alignment of the starting positions, soldiers and workers of Tribe 2 were able to use the extra prey to dominate the battle field. The results are shown in Figure 7.

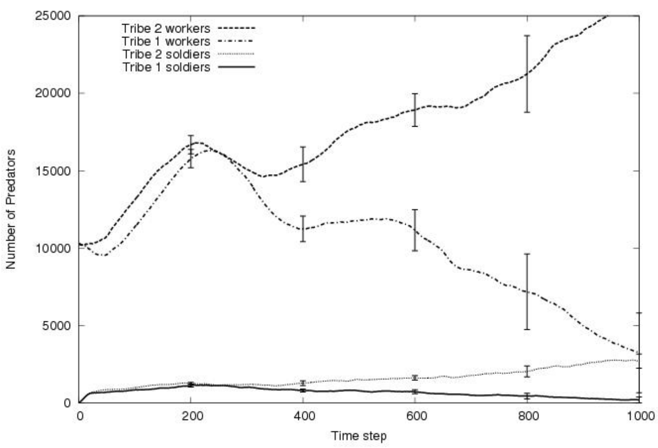

Figure 7: Plot showing predator populations over simulated time when both tribes are able to signal. The plot shows the averages over ten runs with different random number seeds.

6 Experiment 3 – Signals On Side Only

In this experiment, the predators were divided evenly into two competing tribes as described in section 5. However, unlike the previous experiments, Tribe 1 was able to use signals but Tribe 2 was not. Figures 8 and 9 highlight the problems faced by Tribe 2 due to the lack of signals: while the soldiers of Tribe 1 stream towards the battle sites, those of Tribe 2 remain where they were created – scattered randomly and ineffectually across the territory occupied by the tribe. It should be noted that the starting positions in this experiment are identical to those in section 5 above, in which Tribe 2 was always dominant. But in this experiment Tribe 2 was always destroyed due to the lack of signal capability, even though it still retained the advantages of those same starting positions.

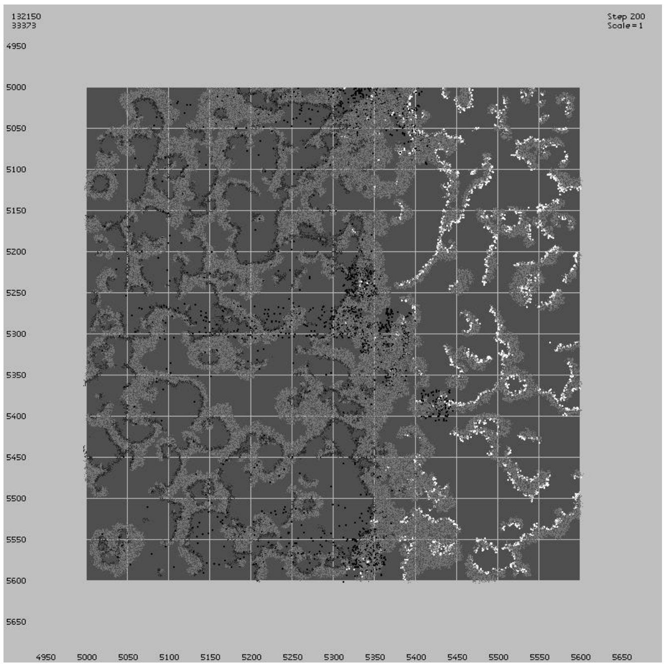

Figure 8: Tribe 1 is able to use signals but Tribe 2 does not. The situation at step 200 shows soldiers of Tribe 1 (black) streaming towards the battle sites whereas those of Tribe 2 (white) remain scattered randomly in or near their starting positions.

7 Experiment 4 – Unequal Forces

In this experiment, the predators were divided evenly into two competing tribes as described in section 5. Both tribes were allowed to use signals but the soldier effectiveness of the two tribes was not equal and was initialised such that soldiers of Tribe 1 had a 70% chance of destroying an adjacent enemy soldier whereas those of Tribe 2 had only a 60% chance of destroying an adjacent enemy soldier.

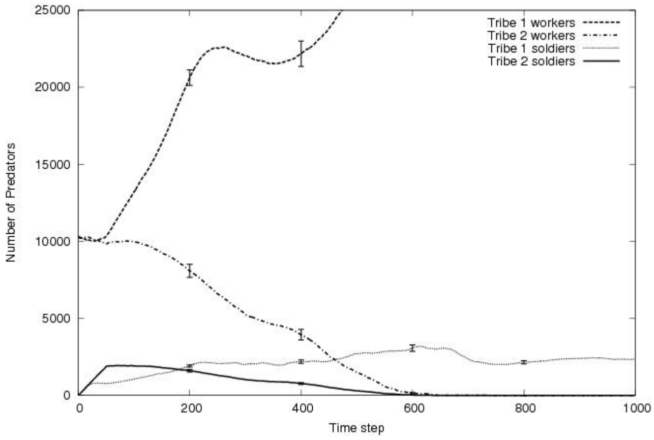

Figure 9: Plot showing predator populations over simulated time when Tribe 1 is able to use signals but Tribe 2 does not. Tribe 2 is rapidly destroyed. The plot shows the averages over ten runs with different random number seeds.

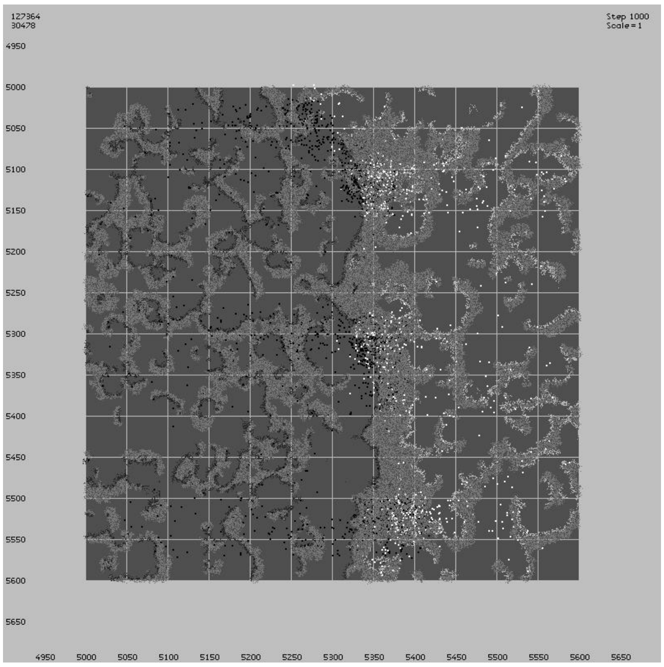

Figure 10: A run in which both tribes are using signalling but the soldiers of Tribe 1 are more effective than those of Tribe 2. The situation at step 1000 shows Tribe 1 soldiers (black) driving back both the soldiers (white) and workers of Tribe 2. Note how the workers of Tribe 1 are colonising prey behind the advancing soldiers.

The situation at step 1000 is shown in Figure 10. Once again, workers of both sides have been destroyed in the battle areas and a large cluster of prey has formed due to the temporary lack of predation. Tribe 1 soldiers are more effective and are driving Tribe 2 soldiers and workers away from the prey cluster and Tribe 1 workers can clearly be seen colonising the edges of the main cluster of prey. The results of this conflict are shown in Figure 11. Once again, Tribe 1 dominates in all runs of the experiment even though the same starting positions are used that enabled Tribe 2 to dominate in earlier experiments. In this case, the advantage given to Tribe 2 by the starting positions (see section 5 above) is nullified by the lack of effectiveness of its soldiers.

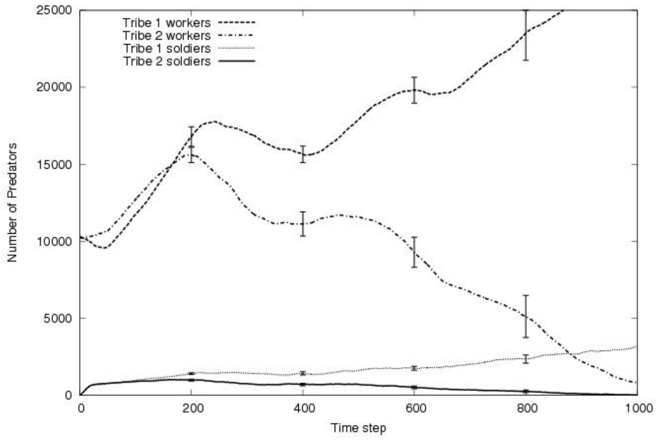

Figure 11: Plot showing predator populations over simulated time when both tribes are using signalling but the soldiers of Tribe 1 are more effective than those of Tribe 2. Tribe 2 is destroyed because Tribe 1 has more effective soldiers. The plot shows the averages over ten runs with different random number seeds.

8 Summary and Conclusion

We have presented results showing the emergent spatial patterns arising from the introduction of a simple long-range communications mechanism in an animat multi-agent model. In conflict situations betwen two communities, the signalling is shown to give a group that possesses the ability a distinct and quantifiable advantage in terms of survivability and population success. We would postulate that this is due to the improved productivity ratio affored to a community that has fewer soldiers that can move to where they are required and this allow productive worker species to harvest resources and populate the species and other essential tasks. Models such as these can give interesting insights into caste specialisation and optimal ratios between different castes for survivability and environment carrying capacity.

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