Computational Science Technical Note **CSTN-090**

Elucidating Soldier and Worker Caste Divisions in an Animat Artificial Life Model

C.J. Scogings and K.A. Hawick

2010

Complex systems such as termite colonies have a macroscopically rich set of emergent behaviours that are thought to emerge solely from microscopic and simple individual agent behaviours. The effect of different castes of termite on the success of a system as a whole is a subtle effect that is difficult to describe analytically, but which can be explored using simulation techniques. We explore the effect of differentiating worker and soldier castes in a predator-prey based animat-agent model. We describe our simulation model and its implementation. The core model comprising a well-established set of microcscopic rules and behavioural priorities normally exhibits statistically predictable boom-bust phenomena with population booms of the predators lagging those of prey. Introducing soldier and worker castes amongst predators can exacerbate and exaggerate the normal model properties. We present results showing the relative advantages to a termite community of having varying proportions of soldiers to worker and we also discuss resource utilisation efficiency and sociological implications of this mode.

Keywords: artificial life; agent technologies; castes; termite colony; animat agents; bio-inspired systems

BiBTeX reference:


```
@INPROCEEDINGS{CSTN-090,
        author = {C.J. Scogings and K.A. Hawick},
        title = {Elucidating Soldier and Worker Caste Divisions in an Animat Artificial
                Life Model},
        booktitle = {International Conference on Genetic and Evolutionary Methods (GEM'10)},
        year = {2010},
        pages = {187-193},
        address = {Las Vegas, USA},
        month = {12-15 July},
        publisher = {WorldComp},
        note = {GEM4365},
        keywords = {artificial life; agent technologies; castes; termite colony; animat
                agents; bio-inspired systems},
        owner = {kahawick},
        timestamp = {2010.05.02}
}
```


Prof Ken Hawick, Computer Science, Massey University, Albany, North Shore 102-904, Auckland, New Zealand.

Technical Report CSTN-090

Elucidating Soldier and Worker Caste Divisions in an Animat Artificial Life Model

C.J. Scogings and K.A. Hawick
Computer Science, Institute for Information and Mathematical Sciences,
Massey University, Albany, P.Bag 102-904 NSMC, Auckland, New Zealand
{c.scogings, k.a.hawick}@massey.ac.nz
Tel: +64 9 414 0800 Fax: +64 9 441 8181

March 2010

Abstract

Complex systems such as termite colonies have a macroscopically rich set of emergent behaviours that are thought to emerge solely from microscopic and simple individual agent behaviours. The effect of different castes of termite on the success of a system as a whole is a subtle effect that is difficult to describe analytically, but which can be explored using simulation techniques. We explore the effect of differentiating worker and soldier castes in a predator-prey based animat-agent model. We describe our simulation model and its implementation. The core model comprising a well-established set of microcscopic rules and behavioural priorities normally exhibits statistically predictable boom-bust phenomena with population booms of the predators lagging those of prey. Introducing soldier and worker castes amongst predators can exacerbate and exaggerate the normal model properties. We present results showing the relative advantages to a termite community of having varying proportions of soldiers to worker and we also discuss resource utilisation efficiency and sociological implications of this mode.

Keywords: artificial life; agent technologies; castes; termite colony; animat agents; bio-inspired systems.

1 Introduction

Termite colonies are known to be highly complex systems with emergent properties and behaviours that are not inherently obvious from the behaviours of individual termites [1]. These behaviours and the fact that termites organise their populations into different castes is well known with detailed observations and comments on the system as a whole dating back to 1927 [2]. Observations and work reported in the biology literature has led to speculation and useful ideas as to the mechanisms and details of this caste specialisation [3]. It appears that one important observed phenomena is that termites separate into soldier and worker castes, which critically depend upon one another for the overall success of the colony [4].

In this article we explore the effect of soldier-worker specialisation using simulated animats - artificially intelligent agensts on a simulated physical space - to explore emergent properties of this bio-inspired system and possible implications for computing systems and other applied simulation areas of interest.

Several Artificial Life simulation models have been reported in the research literature, including [5–7]. These concentrate almost exclusively on the evolution of "digital organisms" and the corresponding emergent macroscopic behaviours and are not particularly concerned with the details of the lives of individual "animats" [8]. More recent multi-agent systems [9] have been used to model a range of topics from trading [10, 11] to battlefields [12].

This article reports use of an existing predator-prey model to investigate caste differentiation in complex Artificial Life communities in which animats are no longer homogenous but perform specialised tasks. Significant research work has been reported on caste differentiation in insect communities in the real world such as termites [13] in which both soldiers and workers have different roles. However, Artificial Life models of such communties tend to restrict themselves to general worker behaviour (for example, see [14, 15]) and

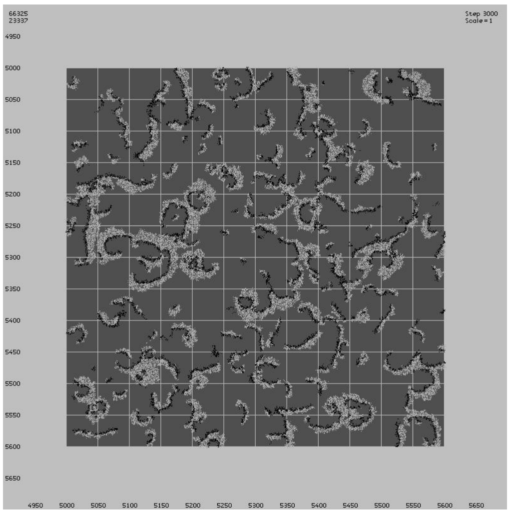

Figure 1: The situation at step 3000 of a typical run showing animats on a square grassed area. Predators are black and prey are light gray. Various macro-clusters, including spiral formations, have emerged. Note how the animats exist almost exclusively on the grassed area.

do not cover the different roles played by the distinct castes within the community.

Our predator-prey model [16] 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 new animat behaviours. In particular we have documented fascinating emergent clusters such as the defensive spirals and other features discussed in [17]. Typical emergent formations can be seen in Figure 1. Since we have a large base of past experimental data to draw upon our model serves as a good platform to investigate new specific bio-inspired effects such as soldier-worker caste division.

A brief overview of the core model is provided in section 2. We then modified the predators in the model to have two distinct castes – discussed in section 3. Three experiments on systems with: a one sided conflict; an even match between two tribes; and a starting configuration designed to compare speciation quality versus quantity, are discussed in sections 4, 5 and 6 respectively. Finally, we suggest some areas for further study in section 7.

2 The Animat Model

Our animat model is based on the notion of two or more 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 [18], 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 [19, 20].

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 trying to breed when there is no breeding parter in the vicinity will fail, 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 below:

Rules for predator animats:

1. breed if health $> 50\%$ and mate adjacent
2. eat prey if health $< 50\%$ and prey adjacent
3. seek mate if health $> 50\%$
4. seek prey if health $< 50\%$
5. randomly move to adjacent position

Rules for prey animats:

1. breed if health $> 50\%$ and mate adjacent
2. eat grass if health $< 50\%$
3. seek mate if health $> 50\%$
4. move away from adjacent predator
5. randomly move to 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); gender (male or female); 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.

Future work could involve reprogramming the animat model with the inclusion of mutation operators to produce genetic effects. We have experimented with changing the order of priority of the rules and thus produced different sub-groups of animats where each sub-group has the same set of rules but with a different priority order [21]. These sub-groups were allowed to compete in order to see which rule set produced the most robust population and it is the rule sets of the winning sub-groups that are now used as the standard rule sets in the current model.

Predators need to consume prey and prey themselves need to eat grass to survive. Whenever an animat successfully executes the "eat" rule, its health value is increased. Grass is placed at various points around the map and this has the effect of containing the prey (and with them, the predators) within the "grassed area". Containing the animats is useful as it prevents the populations becoming very large and unmanageable. It also limits the area of the (otherwise unbounded) grid in which the animats exist. In previous work [22] we have demonstrated that these limitations do not affect the emergent macroscopic behaviours of the model. The experiments in this article take place on a large square "grassed area". This explains why the animat locations have a fairly distinct edge in the diagrams.

The interaction of the animats as they execute their individual rules has produced interesting emergent features in the form of macro-clusters often containing many hundreds of animats. We have analysed and documented these emergent clusters in [17]. The most fascinating cluster that consistently appears is a spiral (containing both predators and prey) and several spirals are visible in the figures in this article.

One benefit of our model is that it can handle very large numbers of animats. Several of the experiments discussed in this article contain over 250,000 animats and of our other simulations have produced over a million animats. These numbers are far in excess of the population figures in other authors' models and allow the study of unique emergent macro-behaviours that would not develop with smaller numbers of animats.

3 Animat Specializations

In our previous experiments, all animats (of one species) have carried the same rule set and executed the same rules. In this article, we experiment for the first time with animats that have specialized tasks. The predators now have two different kinds of animat - the "workers" and the "soldiers". This idea is loosely based on termite colonies [13] but is at a far more abstract level.

Creating, maintaining and operating soldiers is complicated and it is difficult to find the most effective way in which to do this. In our model we initially attempted to create soldiers randomly in which case they appeared all over the map. This technique meant that most of them were never employed as soldiers as they were not adjacent to opposing animats. We then changed the process to that described below, in which workers can change into soldiers if adjacent to enemies (of the other preadtor tribe). This process is not entirely satisfactory and future work will investigate "moving soldiers into position" as occurs in real termite colonies when soldiers are rushed to any site where invaders are breaking into the colony.

In our model, the predators are divided into two distinct "tribes" that compete for resources (prey). Initially, all predators are workers which are standard predator animats as described in section 2. When a worker is adjacent to an animat of the opposing tribe, there is a chance that the worker will change into a soldier. The chance of success of this change differs for each tribe and is controlled by parameters that can be set to different values for each experiment.

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: percentage chance that a worker will be changed to a soldier
- soldier-effectiveness: percentage chance that a soldier will destroy an adjacent enemy soldier

Soldiers do not eat (they ignore the eat rule) 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 [23] we have 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.

4 Experiment 1 – One-Sided Conflict

In this experiment, the predators were divided into two tribes. 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 (refer to the x-axis labels in the figures) and Tribe 2 consisted of all predators with an x-coordinate greater than 5306. 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 demarcated area – much like real termite colonies.

The predators of Tribe 1 consisted of the usual animats described in section 2, i.e. the tribe consisted only of workers with no soldiers. Tribe 2, however, was able to create and maintain soldiers as explained in section 3. This led to the systematic destruction of Tribe 1 as demonstrated by the population graphs shown in Figure 2. The situation at step 3000 is shown in Figure 3. The behaviour and distribution of prey remained unaffected by the competing predator tribes.

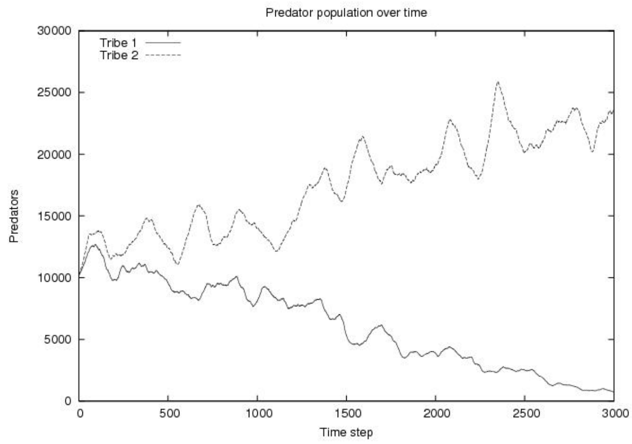

Figure 2: Plot showing predator populations over simulated time. Tribe 2 (upper line) has soldiers whereas Tribe 1 (lower line) does not.

5 Experiment 2 – Even Matching

In this experiment, the predators were divided evenly into two competing tribes as described in experiment 1 in section 4. However, unlike the first experiment, these tribes were given identical capabilities. Both tribes had a 50% chance of a worker changing into a soldier (when adjacent to an enemy animat) and the soldiers of both tribes had a 50% chance of destroying an adjacent enemy soldier. The result was stalemate as shown in the population graphs in Figure 4. The situation at step 3000 is shown in Figure 5. This figure clearly shows that both tribes have gained in certain places but lost territory in others. The reason for a gain or loss in a particular area usually depended on the exact arrangement of prey (resources) in that area. If the predators of one tribe were able to use prey in an area and, at the same time, deny the use of that prey to opposing predators, then they would advance in that area. However, although terri-

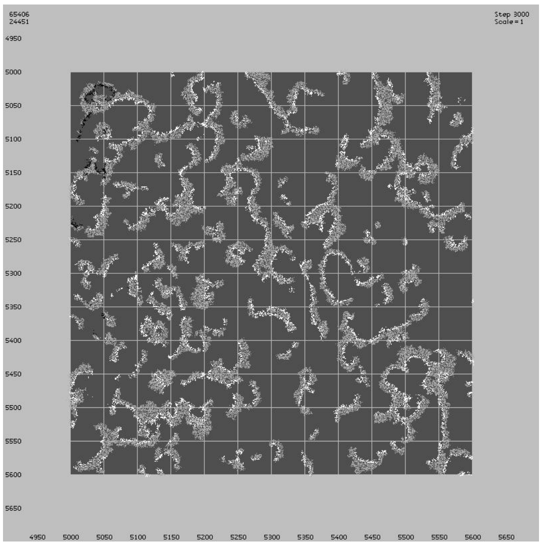

Figure 3: The situation at step 3000 of a run in which predators are split into competing tribes. Tribe 2 (white) includes soldiers but Tribe 1 (black) has none. Tribe 1 has been dramatically reduced and is only able to exist in the top left corner of the grassed area. The behaviour and distribution of prey (light gray) remains unchanged.

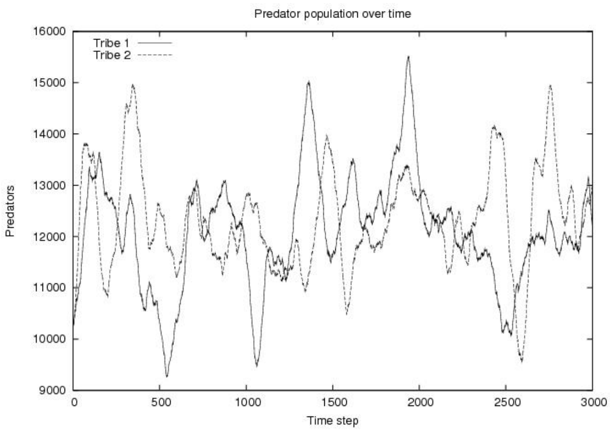

Figure 4: Plot showing predator populations over simulated time during evenly balanced conflict. The soldiers of both tribes have identical capabilities.

tory constantly changes hands, there is no clear gain for either tribe. The behaviour and distribution of prey remained unaffected by the competing predator tribes.

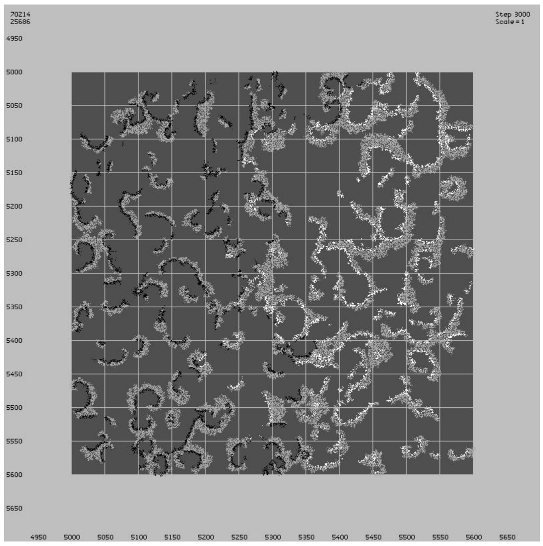

Figure 5: The situation at step 3000 of a run in which predators are split into competing tribes (black and white). Both tribes have the same number of identical soldiers. Stalemate ensues with gains and losses for both sides. The behaviour and distribution of prey (light gray) remains unchanged.

6 Experiment 3 – Quantity vs Quality

In this experiment, the predators were divided evenly into two competing tribes as described in experiment 1 in section 4. Both tribes were also able to create and maintain soldiers as described in experiment 2 in section 5. However in this experiment the capabilities of the two tribes were not equal and were initialised as follows:

- soldier production: Tribe 1 = 100% Tribe 2 = 50%
- soldier effectiveness: Tribe 1 = 50% Tribe 2 = 90%

Thus Tribe 1 had many soldiers but each soldier was at 50% effectiveness whereas Tribe 2 had roughly half the number of soldiers but they were at 90% effectiveness. The results of this conflict can be seen in Figure 6 and show that quality will win over quantity. A relatively smaller number of highly effective soldiers gives a superior advantage than a larger number of weaker soldiers. This trade-off effect is likely governed by the burdens on a colony of supporting a larger soldier population and the difficulties in deploying a larger army “where the action is.”The situation at step 3000 is shown in Figure 7. The behaviour and distribution of prey remains unaffected by the competing predator tribes.

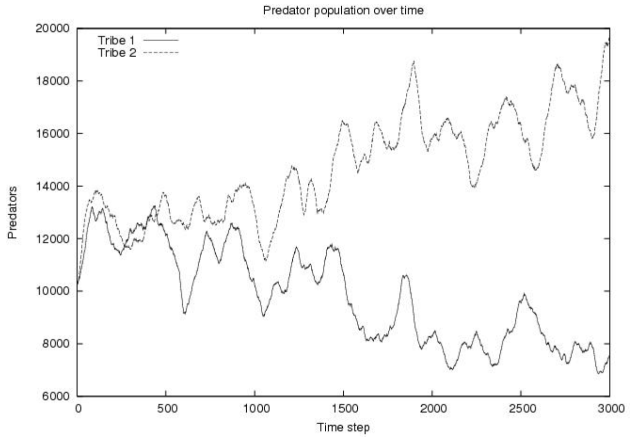

Figure 6: Graph showing predator populations over time when Tribe 1 (lower line) has many inferior soldiers and Tribe 2 (upper line) has about half the number of soldiers but they are of a much higher quality.

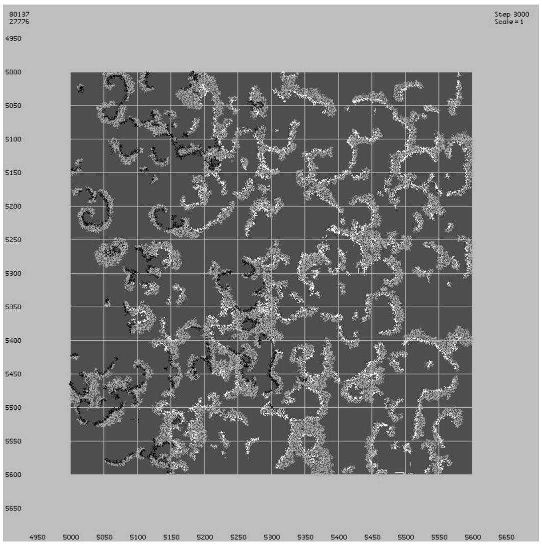

Figure 7: The situation at step 3000 of a run in which predators are split into competing tribes. Tribe 1 (black) has many inferior soldiers. Tribe 2 (white) has fewer soldiers of better quality and is gradually gaining the upper hand.

7 Summary and Conclusions

We have described how soldier-worker caste specialisation can be incorporated into a bio-inspired animat agent simulation model and have reported upon how this affects the success of predator tribes with some different soldier-worker combinations. Most Artificial Life models reported in the literature deploy homogenous animats. In this article we have organised the predators (in a predator-prey model) into two distinct castes – workers and soldiers. Soldiers are the only animats capable of destroying opposing animats but are totally dependent on workers for resources.

We observe that the simulations show boom-bust periodic behaviours - with a period of approximately 500-600 time-steps. This is typical of our model in systems of this size and is not affected by the introduction of soldier-worker castes. However there are clear measureable benefits to a tribe of predators that has the right soldier-worker specialisation balance. We have introduced extra rate-equation parameters into teh stochastic model to control soldier production and effectiveness in the system.

Results show that a community without soldiers can not protect itself against a community that includes soldiers W e also find that communties with soldiers of equal number and capability will expend resources to maintain the soldiers but will not necessarily gain any territory of the other community (a stalemate). It also emerges that quality is superior to quantity in terms of the soldier caste effectiveness parameter. Details of the proper ratios appear still contraversial in the biological literature [24, 25], but our observations are not inconsistent with that from real colony systems.

Planned future work will include an investigation into different techniques for breeding and/or training soldiers and attempts to move soldiers to the place where they are most required. We hope to find a suitable bio-inspired mechanism to control the soldier/worker ration automatically, according to the needs of the colony as a whole. These synergistic and symbiotic effects have proved interesting additions to the animat model. We believe the simple rules we have defined could be incorporated into other models and thus used as a bio-inspired processing mechanisms for other optimisation problems apart from population ecological analyses.

References

[1] Bulmer, M.S., Adams, E.S., Traniello, J.F.: Variation in colony structure in the subterranean termite reticulitermes flavipes. Behav. Ecol. Sociobiol. **49** (2001) 236–243

[2] Heath, H., Wilbur, B.C.: The development of the soldier caste in the termite genus termopsis. Biological Bulletin **LIII** (1927) 145–154

[3] Tarver, M.R., Schmetz, E.A., Rocca, J.R., Scharf, M.E.: Effects of soldier-derived terpenes on sol-

dier caste differentiation in the termite reticulitermes flavipes. J. Chem. Ecol. **35** (2009) 256–264

[4] Yamamura, N.: Different evolutionary conditions for worker and soldier castes: Genetic systems explaining caste distribution among eusocial insects. J. Theor. Biol. **161** (1993) 111–117

[5] Adami, C.: On modeling life. In Brooks, R., Maes, P., eds.: Proc. Artificial Life IV, MIT Press (1994) 269–274

[6] Holland, J.H.: Echoing emergence: Objectives, rough definitions, and speculations for echo-class models. In Cowan, G.A., Pines, D., Meltzer, D., eds.: Complexity: Metaphors, Models and Reality. Addison-Wesley, Reading, MA (1994) 309–342

[7] Tyrrell, T., Mayhew, J.E.W.: Computer simulation of an animal environment. In Meyer, J.A., Wilson, S.W., eds.: From Animals to Animats, Proceedings of the First International Conference on Simulation of Adaptive Behavior. (1991) 263–272

[8] Wilson, S.W.: The animat path to AI. In Meyer, J.A., Wilson, S., eds.: From Animals to Animats 1: Proceedings of The First International Conference on Simulation of Adaptive Behavior, Cambridge, MA: The MIT Press/Bradford Books (1991) 15–21

[9] Komosinski, M., (Eds.), A.A.: Artificial Life Models in Software. Second edn. Springer (2009) ISBN 978-1-84882-284-9.

[10] Owen, M., Lee, L., Sewell, G., Steward, S., Thomas, D.: Multi-agent trading environment. BT Technology Journal **17** (1999) 33–43

[11] Cliff, D., Bruten, J.: Animat market - trading interactions as collective social adaptive behaviour. Adaptive Behaviour **7** (1999) 385–414

[12] Ilachinski, A.: EINSTein: A multiagent-based model of combat. In Komosinski, M., Adamatzky, A., eds.: Artificial Life Models in Software. (2009) 259–315

[13] andYusuke Ikemoto, M.I., ToruMiura, HajimeAsama: Atermiteinternalstatemodelforelucidatingcastedifferentiation. In: SICE Aunnual Conference, The University Electro-Communications, Japan (2008) 142–145

[14] Wilensky, U.: Netlogo user community models. Available from http://ccl.northwestern.edu/netlogo/ (1999)

[15] Wu, B., Zhang, H., Ni, X.: Simulation of Artificial Life of Bee's Behaviours. Number 4689 in LSMS. In: Lecture Notes in Bioinformatics. Springer (2007) 38–45

[16] Scogings, C.J., Hawick, K.A., James, H.A.: Tools and techniques for optimisation of microscopic artificial life simulation models. In Nyongesa, H., ed.: Proceedings of the Sixth IASTED International Conference on Modelling, Simulation, and Optimization, Gabarone, Botswana (2006) 90–95

[17] Hawick, K.A., Scogings, C.J., James, H.A.: Defensive spiral emergence in a predator-prey model. Complexity International (2008) 1–10

[18] Hawick, K.A., James, H.A., Scogings, C.J.: Manual and semi-automated classification in a microscopic artificial life model. In: Proc. Int. Conf. on Computational Intelligence (CI'05), Calgary, Canada. (2005) 135–140

[19] Lotka, A.J.: Elements of Physical Biology. Williams & Williams, Baltimore (1925)

[20] Volterra, V.: Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. Mem. R. Accad. Naz. dei Lincei, Ser VI **2** (1926)

[21] Hawick, K.A., James, H.A., Scogings, C.J.: Roles of rule-priority evolution in animat models. In: Proc. Second Australian Conference on Artificial Life (ACAL 2005), Sydney, Australia (2005) 99–116

[22] Scogings, C.J., Hawick, K.A.: Global constraints and diffusion in a localised animat agent model. In: Proceedings of the IASTED Int. Conf. on Applied Simulation and Modelling, Corfu, Greece (2008) 14–19

[23] Scogings, C., Hawick, K.: Altruism amongst spatial predator-prey animats. In Bullock, S., Noble, J., Watson, R., Bedau, M., eds.: Proc. 11th Int. Conf. on the Simulation and Synthesis of Living Systems (ALife XI), Winchester, UK, MIT Press (2008) 537–544

[24] Waller, D., Fage, J.L.: Environmental influence on soldier differentiation in coptotermes formosanus shiraki (rhinotermitidae). Insectes Sociaux, Paris **35** (1988) 144–152

[25] Long, C., Thorne, B., Breisch, N.: Termite colony ontogeny: a long-termassessment of reproductive lifespan, caste ratios and colony size in reticulitermes flavipes (isoptera: Rhinotermitidae). Bulletin of Entomological Research **93** (2003) 439–445