Computational Science Technical Note **CSTN-094**

Emergent Societal Effects of Crimino-Social Forces in an Animat Agent Model

C. J. Scogings and K. A. Hawick

2009

Societal behaviour can be studied at a causal level by perturbing a stable multi-agent model with new microscopic behaviours and observing the statistical response over an ensemble of simulated model systems. We report on the effects of introducing criminal and law-enforcing behaviours into a large scale animat agent model and describe the complex spatial agent patterns and population changes that result. Our well-established predator-prey substrate model provides a background framework against which these new microscopic behaviours can be trialled and investigated. We describe some quantitative results and some surprising conclusions concerning the overall societal health when individually anti-social behaviour is introduced.

Keywords: animat agent; societal impact; social behaviour; emergence; complexity; adaptive system

BiBTeX reference:

```
@INPROCEEDINGS{CSTN-094,
        author = {C. J. Scogings and K. A. Hawick},
        title = {Emergent Societal Effects of Crimino-Social Forces in an Animat Agent
                Model},
        booktitle = {Proc. 4th Australiasian Conference on Artificial Life (ACAL'09)},
        year = {2009},
        number = {5865},
        series = {LNAI},
        pages = {191-200},
        address = {Melbourne, Australia.},
        month = {1-4 December},
        publisher = {Springer},
        note = {ISBN 978-3-642-10426-8},
        keywords = {animat agent; societal impact; social behaviour; emergence; complexity;
                adaptive system},
        owner = {kahawick},
        timestamp = {2009.09.06}
}
```

Technical Report CSTN-094

Emergent Societal Effects of Crimino-Social Forces in an Animat Agent Model

C.J. Scogings and K.A. Hawick
Computer Science, Massey University, Albany
North Shore 102-904, Auckland, New Zealand
Email: {c.scogings, k.a.hawick}@massey.ac.nz
Tel: +64 9 414 0800 Fax: +64 9 441 8181

June 2009

Abstract

Societal behaviour can be studied at a causal level by perturbing a stable multi-agent model with new microscopic behaviours and observing the statistical response over an ensemble of simulated model systems. We report on the effects of introducing criminal and law-enforcing behaviours into a large scale animat agent model and describe the complex spatial agent patterns and population changes that result. Our well-established predator-prey substrate model provides a background framework against which these new microscopic behaviours can be trialled and investigated. We describe some quantitative results and some surprising conclusions concerning the overall societal health when individually anti-social behaviour is introduced.

Keywords: animat agent; societal impact; social behaviour; emergence; complexity; adaptive system.

1 Introduction

Modelling sociological phenomena at a macroscopic level is a non-trivial problem generally, and understanding anti-social behaviours such as criminal tendencies is particularly difficult [1]. Some attempts have been made to develop computer simulations of criminal phenomena [2] and these have had some success in studying spatial patterns of criminal activity [3, 4]. Intelligent agent systems work in the area of criminal social simulation [5] has focused on dynamically generated beliefs and desires and on the use of general social reasoning mechanisms and models [6, 7] which have been difficult to scale up to large systems.

We have attempted to incorporate simplified anti-social or criminal behaviours at a microscopic level in a large scale Artificial Life (ALife) model system with the expectation that such behaviours would modify emergent macroscopic behaviours of the system as a whole. Several sophisticated artificial ALife simulation models exist, including [8–10]. These concentrate almost exclusively on the evolution of "digital organisms" and the corresponding emergent macro-behaviours. They are less concerned with the microscopic details of the lives of individual "animats" [11].

Our predator-prey model [12] has been refined over a period of several years and has proved a useful substrate model against which to study new behaviours such as trading [13] and species segregation [14]. 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.

The predator-prey mix of animats 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 $10^5 - 10^6$ individual animats. Typical emergent formations can be seen in the screenshot of our model shown in Figure 1. Predator animats are shown in black and prey in white against a green grass background upon which prey animats graze.

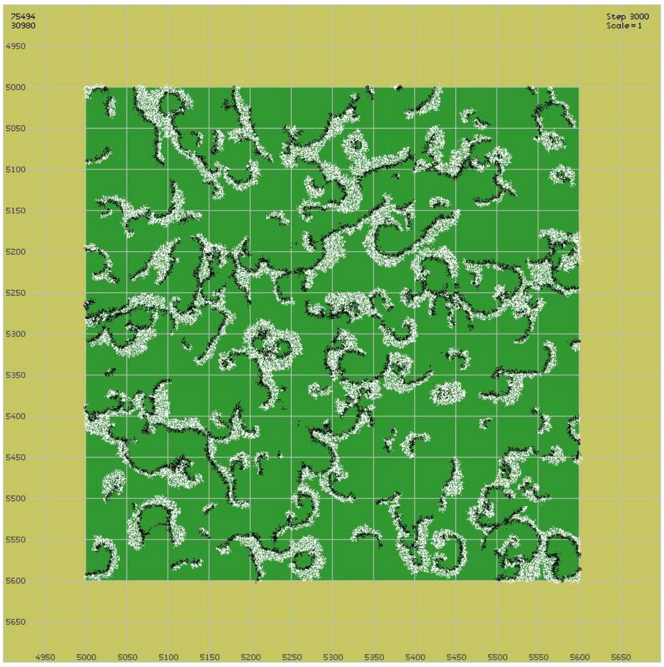

Figure 1: The situation at step 3000 of a typical run (without criminal or law-enforcement agents) showing animats on a square grassed area. Predators are black and prey are white. Various macro-clusters, including spiral formations, have emerged.

The desert border provides a practical model throttle on the system size. The figure shows some of the typical spatial animat formations that form, develop and dissipate in the life-cycle of the model.

Few Artificial Life models have been used to study the effects of "higher-order" social interactions. In this article, we study the effects on animat population and behaviour of introducing criminals into their community. We also introduce "police" that can control the criminals. In this paper we focus on how the collective animat behaviours change when first a criminal sub-population is introduced and secondly when some sort of law-enforcement animats are introduced. We describe the workings of our numerical simulation model in section 2. We present details on how to introduce criminals and police into the animat community in sections 3 and 4 and we give some selected results – in terms of model system snapshots as well as population and behaviour measurements, in section 5; We offer some tentative conclusions and areas for further work in section 6.

2 The Animat Model

Our model consists of two species of interacting animats – the predators and the prey. At each time step of the model, every animat updates and records its current state which consists of: current health; current age; and an x-y location in their 2-dimensional world. When an animat is first created the current age is set to zero. The age is incremented at every time step and when it reaches a pre-set maximum for the species the animat "dies of old age" and is removed.

All animats in the model have a "current health" value. This value (in some ways analogous to "internal energy") is reduced each time-step and if it reaches zero the animat "starves to death". If an animat eats something (predators eat prey and prey eat "grass") then the current health value will be increased by a certain amount, although it may never be increased past the maximum health value which is predetermined for each animat species. The concepts of health values and animats eating behaviours are discussed in [15].

Prey eat only "grass" which is assumed to be continually replenished although we can adjust this rate and can also adjust the spatial pattern of grass which 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 too large and unmanageable and also limits the area of the (otherwise unbounded) grid in which the animats exist. In previous work [16] we have demonstrated that these limitations do not affect the emergent macro-behaviours of the model. The experiments discussed in this article take place on a large square "grassed area" which explains why the animat locations have a fairly distinct edge in the diagrams.

Predators eat only prey and other things being equal we can reproduce the well known boom-bust limit cycles predicted by predator-prey models such as the Lotka-Volterra coupled differential equations [17, 18] and their spatial variants [19]. Although the model is synchronous, animats are updated in a random order which we found adequate to remove any spatial artifacts from sweep order. The process is thus a two-phase system in which the variables for all animats are updated after all checks have been made and all rules have been executed. The two-phase system was developed in order to ensure fairness across all the animats in the model and a full discussion of alternative updating systems is available in [20].

Every animat carries a small set of rules that govern its behaviour and this rule set is passed on unchanged to any offspring. It is possible to allow mutations to rules and to introduce genetic algorithms into the model but an important feature of our work is to make small, well-defined changes to the microscopic model and measure the effects of those changes. We have experimented with changing the order (priorities) of the rules and have investigated which rule sets generate the most successful animat groups [12]. Table 1 summarises the animat rules.

Rule	**Predator**	**Prey**	**Conditions**
Move Away	No	Yes	overcrowded prey
Breed	Yes	Yes	female with adjacent male; birth conditions
Eat prey	Yes	No	health $< 50\%$; adjacent prey
Flee predator	No	Yes	adjacent predator
Graze	No	Yes	health $< 50\%$; not crowded; requires grass
Seek Mate	Yes	Yes	health $> 50\%$; no adjacent mate
Seek Prey	Yes	No	health $< 50\%$; no adjacent prey
Random move	Yes	Yes	

Table 1: Rules currently used in the model. A rule is only executed if the conditions are met; otherwise that rule is ignored. The birth conditions are discussed below.

Breeding only has a certain chance of success. This is a simple alternative to factoring in a host of complicated parameters including birth defects, nutrition, adequate shelter and so on. For these experiments the chance of a successful birth was set to 15% for predators and 80% for prey. The prey conditions involving crowding were introduced to prevent prey forming enormous clusters in any area of the grid that happened to be temporarily free of predators. If a prey animat has k or more adjacent neighbours, it is deemed to be "crowded" and can not eat grass (an abstract simulation of "over grazing"). For these experiments k was set to 7.

Rules are considered in a strict priority order. Each time-step, every animat attempts to execute the first rule in its rule set. However, most rules have conditions so can often not be executed. For example, prey will only move away from a predator if a predator is actually adjacent. If the conditions for the first rule can not be satisfied, the animat attempts to execute the next rule in the set and so on.

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 [21]. The most fascinating cluster that consistently appears is a spiral and several spirals are visible in Figure 1. One benefit of our model is that it can handle very large numbers of animats. Several of the experiments discussed in this article contain of the order of 200,000 animats and other simulations have produced over a million animats. These numbers are far in excess of the population figures in other models and allow the study of unique emergent macro-behaviours that would not develop with smaller numbers of animats.

3 Simulation Experiment 1 - Introducing Criminals

We conducted some experiments to see if any macro-behaviours emerged when criminals appeared in society. During these experiments, the prey animats remained unchanged, i.e. prey exists simply to provide resources for the predator community.

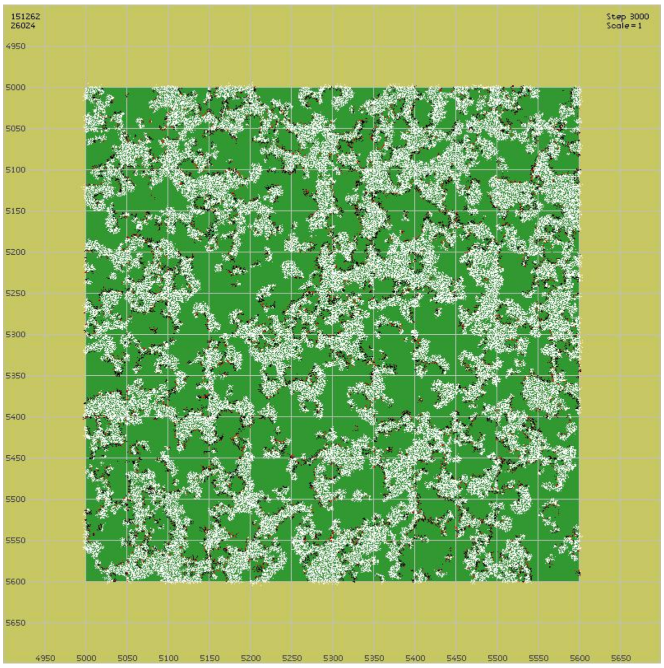

Figure 2: The situation at step 3000 of a typical run when criminals have been introduced. Predators are black and prey are white. The predator population is 26,024 which is less than the 30,980 shown in the control situation in Figure 1 and approximately 25% of the predators are criminals. The prey population of 151,262 is almost exactly double the 75,494 prey in Figure 1. Spirals and other interesting formations continue to emerge.

The first experiment was to introduce criminals into predator society. A criminal is defined as a predator that attacks an adjacent predator and removes some of the neighbour's health points. Health points are essential to life so in many cases the removal of health points can lead to an early death for the victim. In order to keep things simple, the following rules were used. Criminals are "born". It is not possible for a predator to change from non-criminal to criminal or vice versa. A non-criminal parent has a 15% chance of producing criminal offspring whereas a criminal parent has a 80% chance of producing criminal offspring. A neighbour is attacked at random - the neighbour could be "wealthy" (have maximum health points) or "poor" or, in fact, a criminal themselves. Attacks always succeed. The victim always loses 40% of its current health points.

In future work it may prove interesting to vary some of these parameters, e.g. criminals may target wealthy victims or not all attacks may succeed. Because some of the victims died (due to lack of health points) the overall population of predators dropped and this, in turn, caused an increase in the prey population. A typical situation at step 3000 in one of these runs can be seen in Figure 2. During these runs the number of criminals remained stable at approximately 25% of the total predator population.

4 Simulation Experiment 2 - Introducing Police

The second experiment was to introduce police into the predator society which already contained criminals (introduced in first experiment). Police are not "born". Instead police are ordinary predators that are appointed as police under particular circumstances. The rules governing the appointment of a police (predator) are as follows. The predator must be adjacent to a predator that is the victim of a criminal attack. The predator must be neither

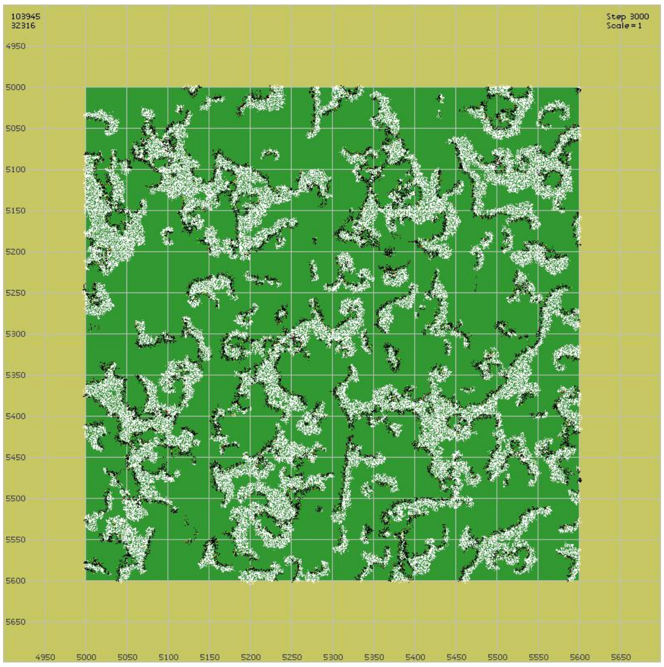

Figure 3: The situation at step 3000 of a typical run when both police and criminals have been introduced. Predators are black and prey are white. The predator population is 32,316 which is higher than the 26,024 shown in Figure 2. Approximately 6% of the predators are police and 2.5% are criminals. The prey population is 103,945 which is lower than the 151,262 in Figure 2.

criminal nor police. There is then only a 30% chance that the predator is appointed as police.

Once a predator is appointed as police it remains police for the rest of its existence. If a police predator is adjacent to a criminal, the criminal is destroyed. Future work may investigate alternatives to this. Because criminals are destroyed the runs in this experiment tended to have higher populations of predators than those when criminals were introduced without a police presence. A typical situation is shown in Figure 3. During these runs the number of police and criminals remained stable at approximately 5.9% and 2.5% of the total predator population respectively. Thus the presence of the police reduced the criminal population from 25% to 2.5%.

5 Simulation Results

In our previous work we have found that measurements on the bulk animat population gave a good metric for the success of a particular agent society in terms of the mean sustainable population level. Predator-prey systems typically exhibit boom-bust periodic fluctuations, and our model populations usually settle down to oscillate about a mean representative value. Predator populations lag prey and the grosser uncertainties in these measurements due to microscopic spatial fluctuations can be dampened out upon averaging over independent model runs that were starting with microscopically different but statistically similar initial conditions.

The introduction of criminals and police had a marked effect on the animat populations. When criminals were introduced the predator population suffered an initial dramatic drop but then recovered to almost the same levels as in the control simulations (where there were no criminals present) – see Figure 4(left). An unexpected result was that the predator population (with both criminals and police present) is higher than the original control population. This occurs because the initial attacks by criminal predators cause a drop in predator population which enables an increase in the prey population – Figure 4(right) which, in turn, can sustain a higher number of predators.

Table 2 shows some of the measured animat activities during the simulations – based upon the frequency with

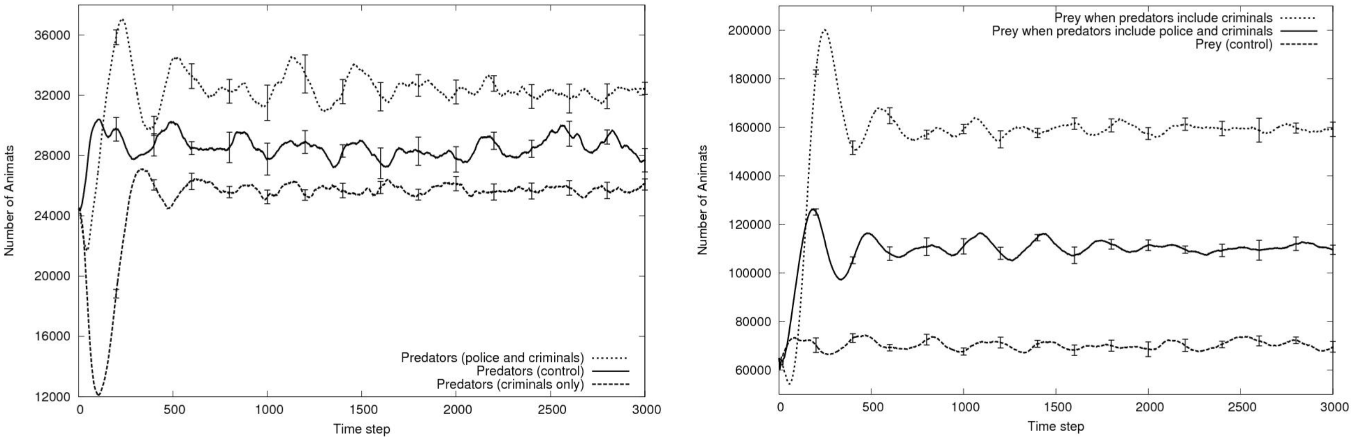

Figure 4: Predators (left) and Prey (right) populations averaged over 10 independent runs of the model in three different types of simulation - the control, the introduction of criminals and the introduction of both criminals and police. Note the initial dramatic drop in the population when criminals are introduced. Note also the increase in prey population caused by a reduction in the predator population due to attacks by criminals.

which particular rules are executed by animats. Note that the number of animats executing a random move drops when criminal agents are introduced and rises again when police agents are introduced.

Rule	**Control(M)**	**Control(F)**	**Crim(M)**	**Crim(F)**	**Pol(M)**	**Pol(F)**
Breed		4.5%		5.8%		5.1%
Eat Prey	9.3%	9.2%	17.0%	19.3%	10.3%	10.2%
Seek Mate	4.9%	4.2%	8.5%	6.4%	5.9%	4.6%
Seek Prey	20.8%	20.9%	20.0%	20.6%	19.8%	20.7%
Random move	32.8%	30.9%	27.3%	23.4%	32.0%	29.8%
new born	32.2%	30.3%	27.3%	24.5%	32.1%	29.5%

Table 2: This table shows what percentage of the predator population used a particular rule during time step 3000. “Crim” indicates that criminals are present. “Pol” indicates that police and criminals are both present. (M) and (F) denote male and female respectively. “new born” refers to animats created in this time step that therefore do not execute a rule.

Figure 5 shows the typical age distribution of animats. Introducing criminal agents into the population shifts the distribution in favour of younger animats, presumably as older less healthy animats are more vulnerable to having their health points stolen. Introducing police agents mostly restores the distribution to its control level before anti-social agents were introduced at all.

6 Discussion and Conclusions

We have reported upon simulation experiments to introduce criminal and law-enforcement behaviour into animat agent models. We have introduced anti-social and police enforcement microscopic behaviours amongst the predator agents which are the higher-level artificial life-forms in our system.

Our data shows some surprising results concerning the overall animat population when first criminals and subsequently police agents are introduced. Introducing criminals appears to *improve* the general level of animat population and subsequently introducing police agents improves it even further.

An examination of the agent age distribution and rule execution frequencies suggests that criminal agents are serving to remove old and unhealthy animats from the population. While this might be politically unappealing it is an emergent numerical consequence of the model rules. Happily the introduction of police does yield a

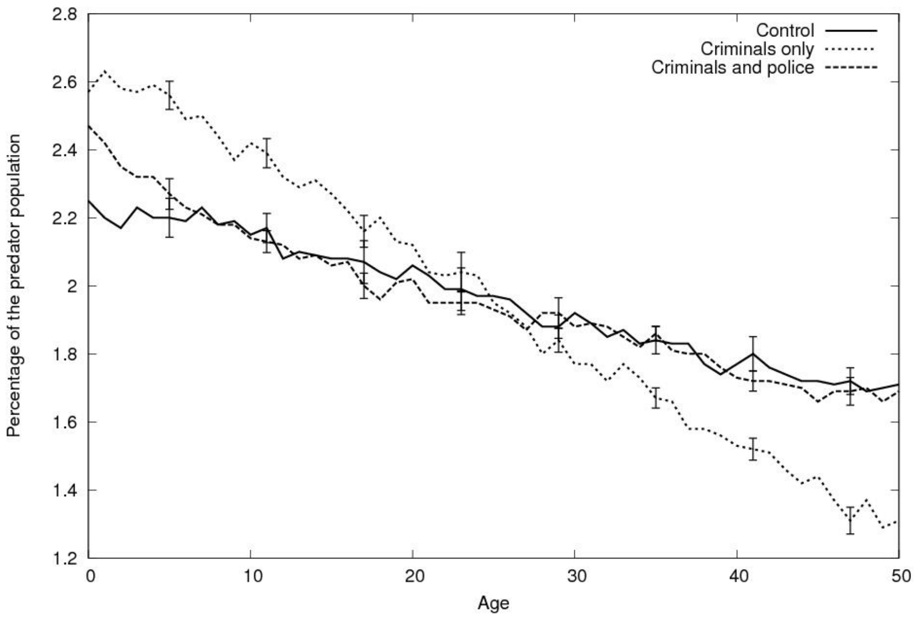

Figure 5: Graph showing the spread of ages across the predator population at time step 3000. These figures are based on an average of 10 runs for each situation.

sociologically more intuitive and politically appealing result and further increases the sustainable mean animat populations whilst restoring the age distribution to its control experiment levels.

We believe numerical experiments such as these, involving dispassionate numerical microscopic parameters, are a useful means to exploring sociological phenomena at a bulk level in large scale systems that approach the size of realistic social systems.

References

[1] Bartol, C.R.: Criminal Behaviour: A Psychosocial Approach. 6th edn. Number ISBN 0130918377. Prentice Hall (2002)

[2] Brantingham, P.L., Brantingham, P.J.: Computer simulation as a tool for environmental criminologists. Security Journal **17** (2004) 21–30

[3] Furtado, V., Melo, A., Menezes, R., Belchior, M.: Using self-organization in an agent framework to model criminal activity in response to police patrol routes. In: Proc. FLAIRS Conference. (2006) 68–73

[4] Furtado, V., Melo, A., Coelho, A., Menezes, R.: A crime simulation model based on social networks and swarm intelligence. In: Proc. 2007 ACM symposium on Applied computing. (2007) 56–57

[5] Bosse, T., Charlotte, Treur, G.J.: Cognitive and social simulation of criminal behaviour: the intermittent explosive disorder case. In: Proc. 6th Int. Joint Conference on Autonomous Agents and Multiagent Systems. Number ISBN 978-81-904262-7-5, Honolulu, Hawaii (2007)

[6] Guye-Vuilleme, A., Thalmann, D.: A high-level architecture for believable social agents. Virtual Reality **5**(2) (2000) 95–106

[7] Kats, Y.: Intelligent software design: Challenges and solutions. In: Proc. EEE Intemtional Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications. (September 2003) 468–471

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

[9] 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

[10] 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

[11] 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

[12] 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 (December 2005) 99–116

[13] Scogings, C., Hawick, K.: Intelligent and adaptive animat resource trading. In: Proc. 2009 International Conference on Artificial Intelligence (ICAI 09) Las Vegas, USA. Number CSTN-076 (13-16 July 2009)

[14] Hawick, K., Scogings, C.: Spatial pattern growth and emergent animat segregation. Technical Report CSTN-078, Massey University (February 2009)

[15] Scogings, C.J., Hawick, K.A., James, H.A.: Tuning growth stability in an animat agent model. In: Proceedings of the 16th IASTED International Conference in Applied Simulation and Modelling (ASM 2007). (29-31 August 2007) 312–317

[16] Scogings, C.J., Hawick, K.A.: Global constraints and diffusion in a localised animat agent model. In: Proc. IASTED Int. Conf. on Applied Simulation and Modelling, Corfu, Greece (23-25 June 2008) 14–19

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

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

[19] Gallego, S.: Modelling Population Dynamics of Elephants. PhD thesis, Life and Environmental Sciences, University of Natal, Durban, South Africa. (June 2003)

[20] James, H.A., Scogings, C.J., Hawick, K.A.: Parallel synchronization issues in simulating artifical life. In Gonzalez, T., ed.: Proc. 16th IASTED Int. Conf. on Parallel and Distributed Computing and Systems (PDCS), Cambridge, MA, USA (November 2004) 815–820

[21] Hawick, K.A., Scogings, C.J., James, H.A.: Defensive spiral emergence in a predator-prey model. Complexity International (msid37) (2008) 1–10