Computational Science Technical Note **CSTN-121**

An Investigation into the Effects of Sentinels on Animat Collectives

C. J. Scogings and K. A. Hawick

2011

It is well known that animal groups use sentinels. We model the benefits to a collective by incorporating sentinel behaviour into an existing agent-based model consisting of predator and prey animats. Our model system is large enough to exhibit multi-length and multi-time scale behaviours, and we compare the effects of individual members of the prey species adopting sentinel roles, with the normal boom-bust behaviour of the established model. We record significant changes to animat spatial patterns and population size and demonstrate how such models can be used to enable various "what-if" scenarios and provide interesting insights and allow exploration of situations that would be impossible to measure during field research into real animal groups.

Keywords: animats; spatial agents; sentinels; predator-prey; emergence

BiBTeX reference:

```
@INPROCEEDINGS{CSTN-121,
        author = {C. J. Scogings and K. A. Hawick},
        title = {An Investigation into the Effects of Sentinels on Animat Collectives},
        booktitle = {Proc. Nineteenth IASTED Int. Conf on Applied Simulation and Modelling
                (ASM 2011)},
        year = {2011},
        number = {715-095},
        pages = {221-226},
        address = {Crete, Greece},
        month = {22-24 June},
        publisher = {IASTED},
        note = {CSTN-121},
        doi = {10.2316/P.2011.715-095},
        keywords = {animats; spatial agents; sentinels; predator-prey; emergence},
        owner = {kahawick},
        timestamp = {2011.05.16}
}
```

This is a early preprint of a Technical Note that may have been published elsewhere. Please cite using the information provided. Comments or quries to:

Prof Ken Hawick, Computer Science, Massey University, Albany, North Shore 102-904, Auckland, New Zealand.
Complete List available at: http://www.massey.ac.nz/~kahawick/cstn

Technical Report CSTN-121

An Investigation into the Effects of Sentinels on Animat Collectives

Chris J. Scogings and Ken A. Hawick
Institute for Information and Mathematical Sciences
Massey University - Albany Campus
North Shore 102-904, Auckland, New Zealand
email: {c.scogings, k.a.hawick }@massey.ac.nz

ABSTRACT
It is well known that animal groups use sentinels. We model the benefits to a collective by incorporating sentinel behaviour into an existing agent-based model consisting of predator and prey animats. Our model system is large enough to exhibit multi-length and multi-time scale behaviours, and we compare the effects of individual members of the prey species adopting sentinel roles, with the normal boom-bust behaviour of the established model. We record significant changes to animat spatial patterns and population size and demonstrate how such models can be used to enable various "what-if" scenarios and provide interesting insights and allow exploration of situations that would be impossible to measure during field research into real animal groups.

KEY WORDS
animats; spatial agents; sentinels; predator-prey; emergence.

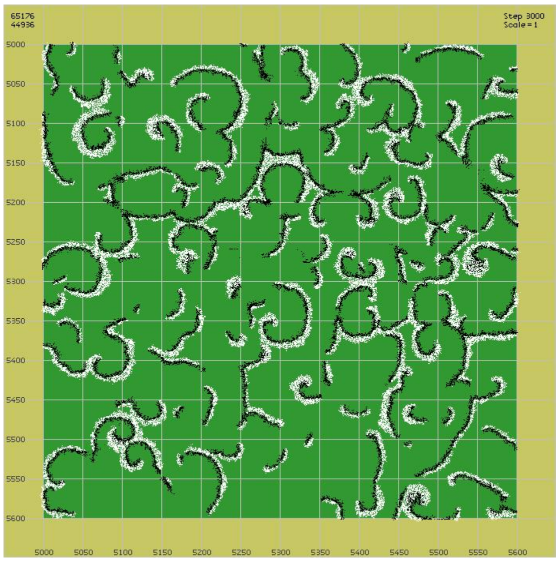

Figure 1: The situation at step 3000 of a typical run showing animats on a square grassed area. Predators are black and prey are white. Various macro-clusters, including spiral formations, have emerged.

1 Introduction

The sentinel behaviour of animals such as meerkats is well known [1, 2] and has frequently been observed in the wild. The collective group of animals will spend most of their time in activities such as foraging, but one or more individuals will adopt a sentinel role. The sentinel will alert the collective of the presence of danger and is in some quantifiable sense sacrificing its own individual feeding time for the apparent greater good of the collective. However, some research [3] has shown that meerkats may stand guard for more selfish reasons as the sentinel is often among the first down a burrow if a predator is detected. It is not obvious how individuals come to the decision to play the sentinel role at a particular time, although it may be nothing more sophisticated a mechanism than those animals already being satiated and pausing to digest.

It is interesting to explore the costs and advantages to the collective of such behaviour. However this is frequently difficult or impossible to do with real animal collectives. For example, it is not possible to analyse a meerkat group that does not employ sentinels. It is possible, however, to use agent-based modeling techniques to construct an abstract model of a collective. Experiments can then be initiated and overall effects can be observed. In addition, various "what-if" scenarios can be constructed that would again be impossible to do with real animal collectives.

In this paper we incorporate sentinel behavior into a well-established predator-prey model [4]. Our model consists of a flat spatial arena, where large numbers of simulated animat agents live, feed, reproduce, flee predators, or hunt prey and ultimately age and die. The model conveniently already models predator-prey effects and comprises a spatial distribution of microscopically determinstic "animats" [5] that play the roles of either predators or of prey. Our model exhibits the boom-bust repetitive cycle of behaviour that is well known with such simulations [6] and from integration of predator-prey equation based models such as the Lotka-Volterra system [7]. Predators hunt and kill prey and overhunting causes the prey population to drop, which is lagged by a dip in the predator pouation, which in turn allows the prey population to recover. A glut of prey is lagged by a temporary over population of predators, and so the cycle continues.

The effect of adding a spatial distribution to the model has been well studied both by ourselves and other researchers. The spatial mix gives rise to complex and emergent patterns of predators and prey such as the defensive spirals and other features discussed in [8]. Typical emergent formations, including spirals, can be seen in Figure 1 where the animats (or spatially located agents) have organised themselves to create a complex set of clusters. Our model is written as a customised and optimised C++ program and as such we are able to manage animat populations of up to one million microscopic individuals. This has proved suffciently large both to avoid extinction fluctuations and also to support macroscopic measurements of the spatial patterns.

In this paper we set up variants of the prey species microscopic rule behaviours so that some prey animats adopt a sentinel role. We then analyse the effects that the presence - or absence - of sentinels has on the model. A brief overview of the predator-prey model is provided in section 2. Section 3 covers how the prey animats were adapted to introduce the use of sentinels. Section 4 provides the results of a typical run of the model without sentinels (the control) and Section 5 analyses a run with sentinels. Section 6 introduces one of a number of possible responses that predators may evolve if faced with a prey population that is making use of sentinels. A summary and conclusions are provided in section 7.

2 The Animat Model

Our predator-prey model employs hundreds of thousands of independent agents (or artificial animals known as "animats") that are spatially located in a two dimensional flat landscape. There are two distinct species of animats – the predators that need to eat prey to survive and the prey that eat "grass".

Every animat has a small set of simple rules that control its behaviour and at each timestep of the model, each animat executes one of its rules. The interaction of the animats produces interesting emergent patterns and macro-behaviours which we have analysed previously [9]. We have developed the model over a number of years and have included a number of refinements in order to maximize efficiency and memory utilization [4].

The rules are listed in the rule set of each animat in priority order. Thus every animat, at every timestep, always attempts to execute rule 1. However, most rules are conditional on certain requirements being met – usually to do with animat health and/or location. If the conditons for a rule can not be met, then that rule is abandoned and the animat will attempt to execute the next rule in the set. The rule sets are listed in Table 1.

The "Breed Rule" is used to create new animats which inherit the rules (and health) of their 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.

Every animat has a small number of state variables including position (coordinates), health and

Table 1: Animat micro behaviour rules.

Rules for predator animats:	Rules for prey 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 any adjacent position	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 any adjacent position

age. When an animat is created its age is initialized to zero. The age is then incremented every timestep and if it reaches the maximum age for the species, the animat "dies of old age" and is removed. Animats start with health initialised to the average of its parents'. Each timestep, health is reduced and the animat "starves to death" if health reaches zero. Health can be increased (up to the maximum health possible for the species) by eating.

Early versions of the model initialised animat health to maximum. However this led to situations in which populations of predators could exist without prey. This occurred because new predators (starting with maximum health) could survive just long enough (without eating) to breed and produce a new set of predators. This problem was solved by starting each animat with the average health of its parents.

Predators eat adjacent prey and prey eat "grass". Grass is placed at fixed locations and is permanently available for prey animats in those locations. The experiments described here take place on a square grassed area. Prey (and hence predators) are unable to survive outside of the grassed area, although individual animats do sometimes move outside the area.

3 Sentinels

In order to perform the experiments described below, a new rule was included in the rule set for prey as follows:

1. **become a sentinel if health $>$ 90%**
2. breed if health $>$ 50% and mate adjacent
3. eat grass if health $<$ 50%
4. seek mate if health $>$ 50%
5. move away from adjacent predator
6. randomly move to any adjacent position

This follows the suggestion made in [3] that a meerkat will take on the sentinel role if it is satiated. An animat on sentinel duty observes all other animats within the detection range – which was set to 15 for these experiments. If a predator is detected, the sentinel alerts all other prey within "signal" range – which was also set to be 15 for these experiments. All alerted prey (including the sentinel) then move one position directly away from the detected predator. This process is depicted in Figure 2.

Note that an animat is thus only on sentinel duty for the duration of a single timestep during which its health will be decreased as usual. It is thus possible (but unlikely) for the same individual to be on sentinel duty for two consecutive timesteps but in general a new group of sentinels will take over at the start of each timestep. Since any individual prey animat can take on (or relinquish) the sentinel role at any time, this means that the average prey animat is often in "signal" range of several sentinels (or possibly none). This means that multiple alerts may be received by an individual. When this happens, only the last alert is acted upon. Future work could investigate other possibilities such as acting on the nearest alert or acting on the alert from the most reliable sentinel. According to [2], meerkats are able to rank sentinels by reliability and may choose to ignore warnings from unreliable sentinels.

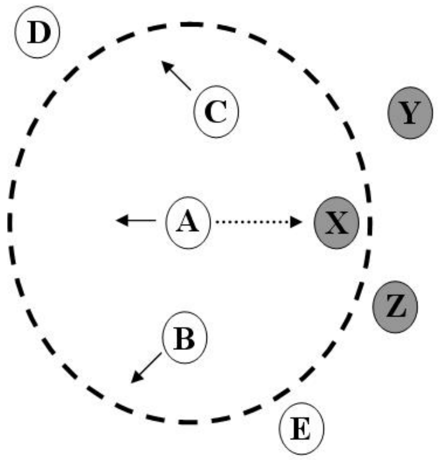

Figure 2: A prey animat on sentinel duty (A) detects a predator (X). Nearby prey (B) and (C) are alerted and the prey animats move away from the detected predator. Predators (Y) and (Z) are not detected (too far away) and prey (D) and (E) are not alerted for the same reason.

Similarly, moving one location away from a detected predator may not always be the best possible escape mechanism and there are occasions when moving away from one predator may cause prey to move closer to another! In fact real meerkats always stay close to a burrow and vanish underground when required. However it would be extremely difficult in an abstract model of this sort to accurately simulate the effect of burrows, predator attempts to enter the burrow, predators waiting for prey to emerge and so forth.

4 Experiment 1 – The Control

The first experiment acted as the control. Thus it contained no prey acting as sentinels and a snapshot of the situation at timestep 3000 reveals the usual pattern of clusters and formations – see Figure 1. The population results are shown in Figure 3. The predator and prey populations settle into the usual boom-bust pattern with the predators lagging just behind the prey. The populations shown are averages over ten runs with different random number seeds.

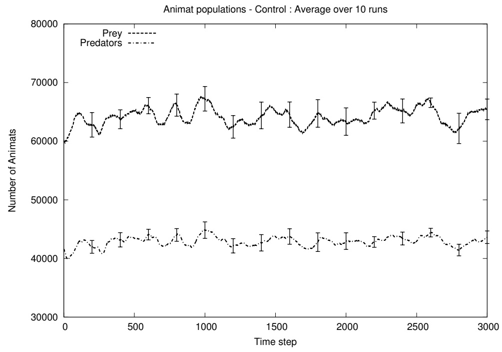

Figure 3: Plot showing animat populations over time in a control situation. No sentinels are present. The plot shows the averages over ten runs with different random number seeds.

5 Experiment 2 – Sentinels

The second experiment introduced prey sentinels as described in section 3. The use of sentinels dramatically increased the prey population and prey can be seen clustering in much denser bands in Figure 4. What is most interesting is that the increase in prey also leads to an increase in predators. Presumably, even though it is more difficult for individual predators to catch prey (due to the presence of the sentinels), there are far more prey around and this benefits the predators. Thus the prey population is more than double that of the control but the predator population is also significantly increased and these population results are shown in Figure 5.

6 Experiment 3 – the Red Queen Principle

In 1973 the evolutionary biologist L. van Valen proposed the Red Queen Principle which states that for an evolutionary system, continuing development is needed in order to maintain its fitness relative to the systems it is co-evolving with.

We have developed a model in which the prey have "evolved" sentinels (although the evolutionary process leading to the use of sentinels was not addressed). Possession of sentinels has allowed the prey to dramatically increase their population. It is conceivable that if prey animats evolved sentinel be-

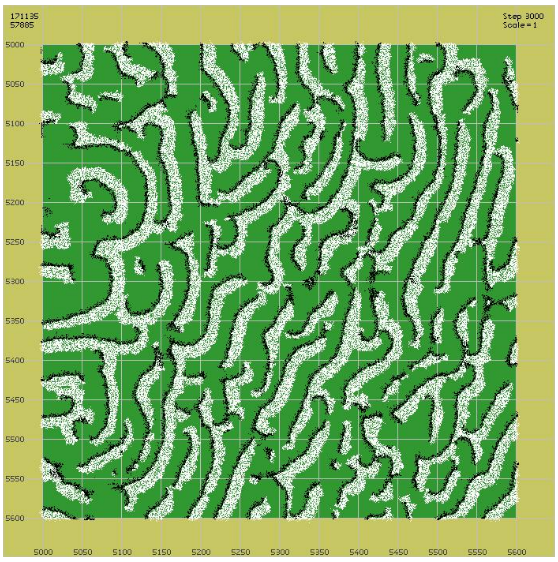

Figure 4: The situation at step 3000 of a run with prey sentinels. Predators are black and prey are white. There are far more prey animats than in Figure 1 and they are clustered in dense bands.

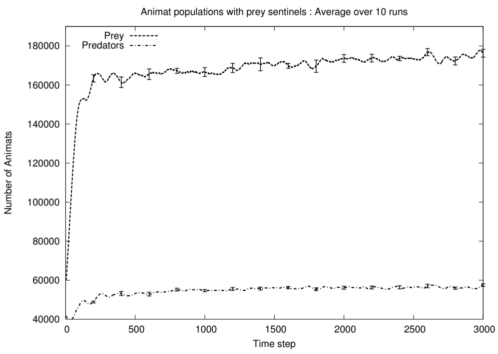

Figure 5: Plot showing the effects of prey sentinels on animat populations. Both prey and predator populations have increased. The plot shows the averages over ten runs with different random number seeds.

haviour that made individual prey more difficult to catch, then predators may evolve some response to this situation. In this experiment the prey population was once again making use of sentinels. However, predators were "improved" and allowed to catch prey that was two locations away (instead of adjacent). This experiment is typical of the "what-if" scenario situations that are possible with this kind of model.

The new predator advantage changed the animat populations to an intermediate situation between the control and the sentinels situation and the population results are shown in Figure 6.

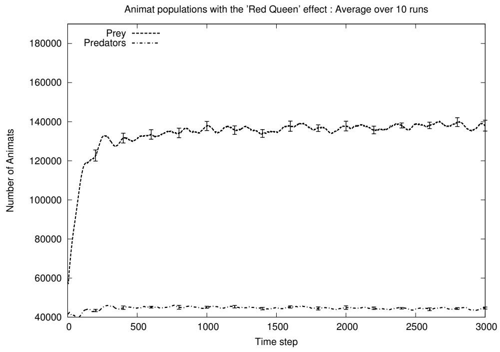

Figure 6: Plot showing animat populations over time when both predator and prey populations are employing enhanced behaviours (the "Red Queen" effect). The plot shows the averages over ten runs with different random number seeds.

Figure 7 shows predator (only) populations for the three experiments. Ironically, the predator population is highest when prey are using sentinels. When predators also employ a new enhancement in an attempt to counter the prey sentinel advantage, the population is returned to almost that of the control – the "Red Queen" effect.

7 Summary and Conclusions

We have shown how sentinel behaviour can be incorporated into an agent-based model consisting of predator and prey animats. Significant changes were noted in both animat spatial location and population levels caused by the introduction of prey sentinels. The prey population expanded considerably. This result was expected but the most interesting (and unexpected) result was a significant and corresponding increase in the size of the predator population.

The changes in population size and density were accompanied by changes in the micro-behaviour of individual animats as shown in Tables 2 and 3. These tables show the percentage of animats executing a particular rule in one timestep. The per-

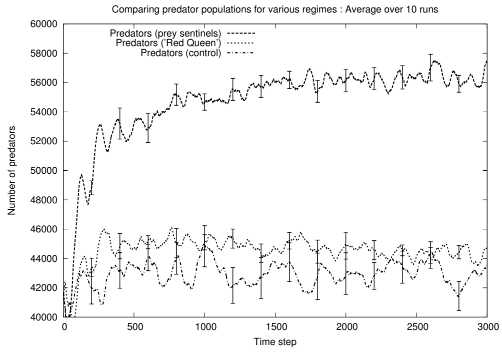

Figure 7: Comparison of predator populations showing the control population (bottom line), the significant increase due to the prey sentinels (top line) and the effects of enhanced hunting ("Red Queen" effect) that almost returns the population to the control situation. The plot shows the averages over ten runs with different random number seeds.

centages are averages over time. Note that "new born" animats do not execute a rule in the time step in which they are created.

Table 2: Changes in rules used by prey.

		Control	Sentinels
	Sentinel	–	5.1%
	Breed	13.9%	12.1%
	Eat grass	13.8%	12.2%
Prey	Seek mate	13.2%	14.9%
	Flee	5.2%	1.7%
	Random	36.2%	32.7%
	New born	17.7%	21.3%

The use of sentinels causes a significant drop in the number of prey executing the "flee from predator" rule. This is because the prey are more likely to have moved away from predators due to early warning from the sentinels and thus are no longer adjacent to predators – the "flee from predator" rule is only executed if a predator is adjacent. There is also a marked increase in the number of new born prey animats because the prey population is able to expand.

The predators change their behaviour less from the control to the situation where the prey are using sentinels. There is, however, an increase in the number of predators seeking prey due to the fact that the prey are more likely to have moved away from predators.

Table 3: Changes in rules used by predators.

		Control	Sentinels
	Breed	2.5%	2.5%
	Eat prey	10.6%	10.5%
Predators	Seek mate	0.6%	0.7%
	Seek prey	28.2%	31.3%
	Random	29.2%	27.6%
	New born	28.9%	27.4%

The use of sentinels allowed prey an "extra move" in that the warning of the sentinel caused prey to move away from predators in addition to any rule that the prey may be executing. We incorporated a "what-if" type of experiment that enabled predators to match this extra move by prey with an "extra move" of their own. The results of this experiment showed that the predator population was almost reduced to the control level and thus demonstrated the "Red Queen" effect.

Future work might include more detailed behaviour by sentinels including the effect of sentinel reliability on the general well being of the collective.

Models such as ours can give interesting insights and allow exploration of situations that are impossible to measure during real field research. We are also working on relating these effects to historical battlefield situation data.

References

[1] Ghiselin, M.T.: Institutional bioeconomics and the division of labor: Reflections on Yarbrough & Yarbrough's paper. Journal of Bioeconomics **1** (1999) 319–322

[2] Ip, C.W.H.: An Investigation into the Affects of Sentinel Reliability on Vigilance in Meerkats. PhD thesis, B.Sc.(Hons), University of Bath (2008)

[3] Clutton-Brock, T.H., Gaynor, D., McIlrath, G.M., Maccoll, A.D.C., Kansky, R., Chadwick, P., Manser, M., Skinner, J.D., Brotherton, P.N.M.: Predation, group size and mortality in a cooperative mongoose, *suricata suricatta*. Journal of Animal Ecology **68** (1999) 672–683

[4] 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

[5] 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

[6] 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

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

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

[9] 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