Computational Science Technical Note **CSTN-084**

Spatial Animat Agent Evolution and Changing Ecological Niches

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2009

Biological systems demonstrate the role of spatial gradients in ecological niche factor but it can be difficult to precisely quantify this. We have incorporated a similar effect into a spatial animat agent model and have used this to measure the change in the fitness success factor when an animat that has evolved for success in one niche is transplanted to a different spatial environmental niche. We describe experiments involving up to one million animat agents of multiple predator and prey sub-species and discuss the implications for animat evolution in large scale models.

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BiBTeX reference:

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@INPROCEEDINGS{CSTN-084,
        author = {C. J. Scogings and K. A. Hawick},
        title = {Spatial Animat Agent Evolution and Changing Ecological Niches},
        booktitle = {IASTED Int. Conference on Artificial Intelligence and Soft Computing,},
        year = {2009},
        pages = {72-77},
        address = {Palma de Mallorca, Spain.},
        month = {7-9 September},
        publisher = {IASTED},
        note = {683-020},
        keywords = {evolution; multi-agent systems; genetic algorithms; animat agents},
        owner = {kahawick},
        timestamp = {2009.09.06}
}
```

Technical Report CSTN-084

Spatial Animat Agent Evolution and Changing Ecological Niches

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Abstract

Biological systems demonstrate the role of spatial gradients in establishing ecological niche factors but it can be difficult to precisely quantify this phenomena. We have incorporated a similar effect into a spatial animat agent model and have used this to measure the change in the fitness success factor when an animat that has evolved for success in one niche is transplanted to a different spatial environmental niche. We describe experiments involving many thousands of animat agents of multiple predator and prey sub-species and discuss the implications for animat evolution in large scale models.

Keywords: evolution; multi-agent systems; genetic algorithms; animat agents.

1 Introduction

Ecological niches are found in biological systems when a species of lifeform – bacterial, viral, or higher level – finds itself in a environment where there is a competitive advantage in having a particular trait. Common traits are the ability to exploit a particular food substance or source of nutrients that is unusually abundant or is not being assimilated by competitors. These ideas are well developed and bacterial species which exploit ecological niches have been well studied in spatially homogeneous and heterogeneous reaction broths [1].

An important observation is that ecological niches can occur even in relatively small biological samples, where there are opportunities for spatial inhomogeneities and structure. Algae can exploit spatial niches at liquid gas boundaries and can form colonies of mats that allow them to survive around these spatial edges. It is not trivial to carry out quantitative spatial experiments on biological systems and it requires a proper spatial structure with long and short range effects to be able to properly simulate spatial ecological niche effects.

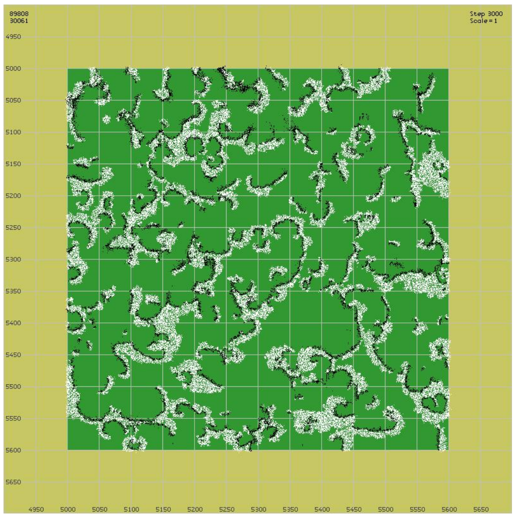

Figure 1: A typical snapshot of the model after 3000 time steps, showing emergent spirals and other spatial structures where predators are shown in black, prey in white, grass (with a grass value of 60) in geen and surrounding desert in sand colour. Only two (*a priori*) predator and prey species are involved.

A number of simulation systems have been established to study artificial life and evolutionary effects. These include Avida [2,3], Tierra [4], ECHO [5] and others [6, 7]. Our model [8] was constructed deliberately to have relatively simple automaton-like microscopic properties but with the potential for a spatial scale that could support macroscopic emergent patterns of $10^5 - 10^6$

individual animats.

Our framework for animal automata (or"animats" [9]) allows individual agents to evolve using a genotype based around some simulated world-relevant microscopic behavioural instructions. Figure 1 shows a snapshot of a typical model run whereby individual groups of predators (black) and prey (white) have organised themselves into macroscopically rich spatial patterns as a result of 3000 time steps of following their individual micro-behaviours.

The model is explained in some detail in section 2 below and has led to the discovery of a number of interesting spatial emergent phenomena such as spiral patterns [10]; herding; segregation and swarming. In this paper we explore the effects of the ecological niches that arise spatially – spontaneously during the course of the model evolution.

Generally we expect situations like that shown in Figure 2 to occur. Through the circumstances of the model evolution or by chance, the particular prey animats in different spatial regions of the model will have slightly different behaviours – denoted for example by different typical inter-animat spacings. These different regions will give rise to different fitness landscape properties for predators, which will typically evolve to suit their local environment or their "ecological niches." Consequently, predators will continue to evolve to favour local conditions, which in turn will cause prey to evolve accordingly and different spatial regions of the model can therefore evolve completely independently, unless the animat herds impinge upon one another. The spatial structure of the animat petri dish or broth constituency can therefore vary substantially in localised pockets in space. Generally we measure bulk properties of the whole system usually averaged over many independent runs or instances of the model system.

For this paper we have investigated what will occur when we transplant animats that have evolved to meet the needs of one ecological niche to a different niche environment. We describe the salient features of our simulation model in section 2 including the spatial flatland or simulated "broth" in which animats can evolve. We present the results of some evolutionary and spatial transplant experiments in section 3, along with a discussion of associated evolutionary issues in section 4. We offer some tentative conclusions and ideas for further study in section 5.

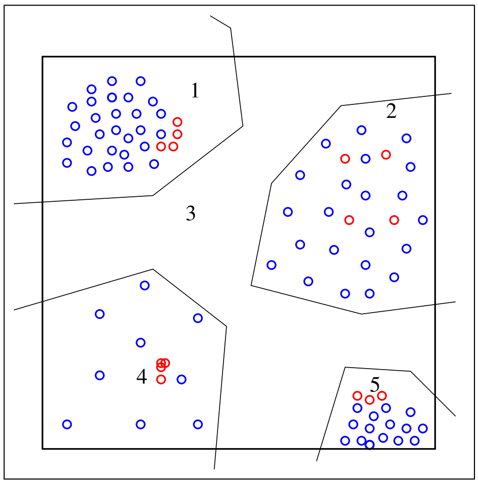

Figure 2: Spatial ecological niches occur initially by chance as local circumstances favour a particular predator sub-species, which then gives rise to locally evolved prey that best survive against them. Pockets of animats evolve independently in potentially disjoint ecological niches that emerge from the spatial structure. An animat bred for success in region 1 is likely to fare badly in region 4 for example.

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. Animats are initially distributed in a random pattern, and as we have reported in previous work [11], 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 know boom-bust population cycles that occur in all predator-prey systems [12, 13]. We typically run our model using a random starting configuration of a few tens of thousands of animats and our simulation apparatus can handle runs of up to $\approx 10^6$ animats for a few thousand time steps. We have generally found that after around 1,000 time steps the system has lost any memory of its initial conditions and that averages made over subsequent time steps tend towards statistically stable and reproducible averages.

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 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 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. The rule set is always listed in priority order and animats will always try and execute rule 1. If rule 1 does not meet the conditions listed in Table 1 then the animat attempts rule 2 and so on. The Breed rule has several conditions including the "birth rate" – a chance that breeding may still fail even if the other conditions are met. The birth rate is a simple abstract way of simulating the effects of a host of complicated factors such as birth complications, availability of shelter, etc. Our model simulation code allows us to histogram the success and failure rates of the different rules at each time step and this has given us insights into different collective phenomena [11].

Animat behaviour is influenced by their environment. In particular prey require "grass" which is placed at specific locations on the map. In the experiments described here, animats exist on a square grassed area. In previous work [14] we found that grass is extremely useful in that it contains prey (and hence predators) and thus restricts populations to manageable levels. Each grass location is allocated a "grass value". A high grass value (60 to 70) means that each prey animat becomes well-fed by eating a small amount of grass. A low grass value (30 to 40) means that an animat has to eat considerably more grass to become well-fed. In "desert conditions" (grass value of zero to ten) animats are not able to survive at all.

When an animat is created, 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'. In early versions of the model, the current health was initialised to the maximum but it was found that this allowed populations on the brink of starvation to continue for prolonged periods. 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. It is useful to define "hungry" to mean that current health is less than half the maximum and "well-fed" to mean that current health is equal to or greater than half the maximum.

3 Evolution Experiments

In most of our prior work we have worked explicitly with particular *a priori* strains of predator and prey animats. In this present paper we make use of a simple evolutionary mechanism as shown in figure 3 to allow animats to evolve using genetic crossover. We have not found it necessary to employ an additional mutation mechanism for the experimental work reported here.

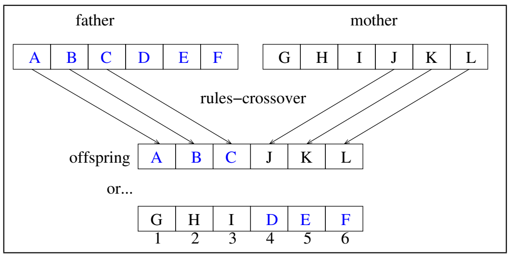

Figure 3: Rules crossover – whereby the controlling rule sequences of the parent animats are combined in a genetic sequence crossover to yield offspring possibilities as shown. In the case of a single offspring, the model chooses randonly with equal probability between the two choices shown.

Genetic crossover has been well described in many other works. Useful explanatory reference works from the perspective of computational models are [6, 15].

3.1 Experiment 1

The first experiment was to run the model with a grass value of 60 which is regarded as a good value that easily enables stable animat populations. Figure 1 shows a typical situation at time step 3000 during one of these runs. During this experiment the prey animats were all clones – the "standard prey" – but the predators were allowed to evolve by crossover only. The experiment was repeated ten times with different random number seeds and the resulting population graphs are shown in Figure 4.

Our rule set genotype mechanism is explained in section 2. Before each run commenced, all predators were initially allocated the rule set **BEMPLR** but the rules were shuffled into a random order. Predators were then allowed to evolve by crossover and after 3000 time steps produced the rule sets shown in Table 2.

3.2 Experiment 2

A new experiment was then conducted which was the same as the initial experiment described above, but a much lower grass value of 30 was used. Figure 5 shows a typical situation at time step 3000 during one of these runs. Once again standard prey (clones) were used and predators were allowed to evolve by crossover from the

Code	Action	Predator	Prey	Conditions
A	move Away	No	Yes	adjacent prey
B	Breed	Yes	Yes	well-fed; adjacent mate; birth rate
E	Eat prey	Yes	No	hungry; adjacent prey
F	Flee predator	No	Yes	adjacent predator
G	eat Grass	No	Yes	hungry; not crowded; requires grass
L	altruistic	Yes	No	adjacent needy predator
M	seek Mate	Yes	Yes	well-fed; no adjacent mate
P	seek Prey	Yes	No	hungry; no adjacent prey
R	move Randomly	Yes	Yes	50% chance of success

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 rate is discussed in the text.

Gender	Rule set	Number	Gender	Rule set	Number
F	EBREPB	2800	M	EPRBMP	2011
F	BEMBMP	2222	M	PBMBPE	1743
F	BERBPE	1943	M	MEBPLR	1468
F	EPBPMR	1859	M	EPREMB	1453
F	BERBPM	1731	M	PREBEP	1420
F	BREPMB	1673	M	BMEEPR	1416

Table 2: Predator rule sets evolved after 3000 time steps on a grass value of 60. Male and female predators have different rule sets. The numbers indicate the number of predators with the same set.

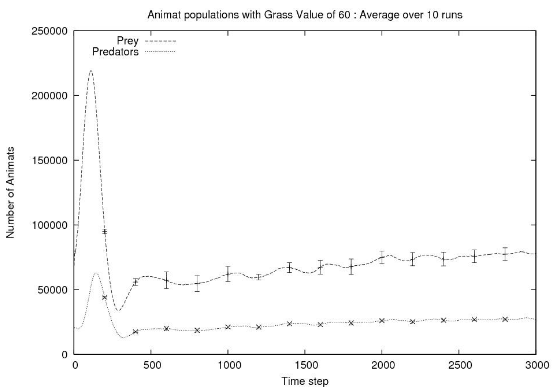

Figure 4: Graph showing population over time when the grass value is 60. These figures are averaged over 10 runs.

same (randomly shuffled) initial rule set. The population graphs for these runs are shown in Figure 6. During these runs, predators evolved to the rule sets shown in Table 3. It is noticeable that the "altruistic rule" (L) features prominently in these rule sets whereas it had all but disappeared from the rule sets evolved when resources were plentiful. This corresponds to previous findings [16] in which we conducted several experiments that showed that altruistic predators (that share health points) were able to survive when resources were too sparse to enable the survival of non-altruistic predators.

3.3 Experiment 3

In order to demonstrate how animats evolve to fit a particular ecological niche the predators that had evolved in a resource-rich régime(a grass value of 60) were placed in a simulation with a low grass value of 30. Every male predator was allocated the rule set EPRBMP and every female predator was allocated the rule set BEMBMP. These are two of the most successful evolved rule sets in Table 2. The parameters were also changed such that evolution no longer took place but all predators were clones (based on gender). The experiment was then run ten times with different random number seeds. The results were dramatic in that in every run the predators died out between time steps 300 and 400. These predators had evolved in an environment where prey was plentiful due to a high grass value and were not able to cope with a situation where prey was not as easily available.

Gender	Rule set	Number	Gender	Rule set	Number
F	EBMELP	1844	M	PMBEPL	1488
F	MEPBPM	1478	M	LEBBPM	1445
F	LEBEPL	1381	M	BMRELP	1342
F	BLPPEM	1143	M	EMBPEM	1130
F	LMEBLP	1015	M	BEMBLP	1028

Table 3: Predator rule sets evolved after 3000 time steps with a low grass value of 30. Male and female predators have different rule sets. The numbers indicate the number of predators with the same set and are consistently lower than the numbers appearing in Table 2.

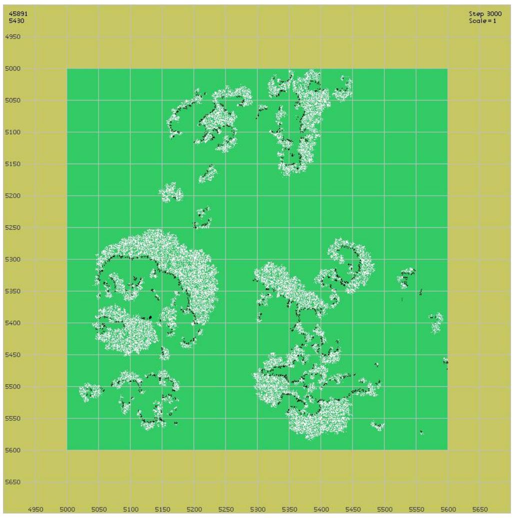

Figure 5: A typical snapshot after 3000 time steps with a low grass value of 30 where predators are black and prey are white. Spirals and other formations continue to evolve. The animat populations in this figure are considerably lower than those depicted in Figure 1 where the grass value is 60.

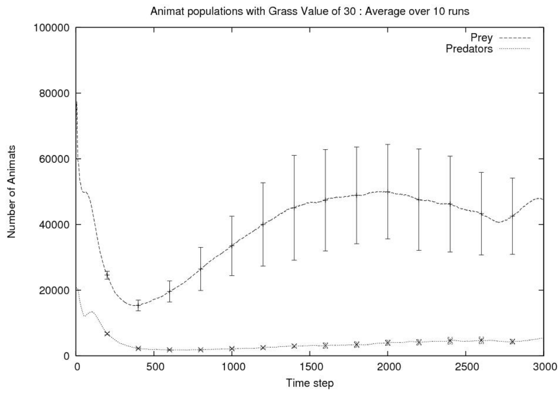

Figure 6: Graph showing population over time with a low grass value of 30. These figures are averaged over 10 runs. Note that the scale on the y-axis is half that of Figure 4.

3.4 Experiment 4

In the final experiment the predators that had evolved in the resource-scarce régime(a grass value of 30) were placed in a simulation with a grass value of 60. These predators were also clones in which all males were allocated the rule set LEBBPM and all females were allocated MEPBPM. Since these predators had evolved in an environment where resources were scarce (grass value of 30) they did not eat or breed as often as those that evolved with a grass value of 60. This, in turn, led to a huge increase in the prey population – see Figure 7.

4 Evolution Discussion

Figure 4 demonstrates how stable animat populations emerge when resources are plentiful. In contrast, when resources are scarce (a grass value of 30) the predators never recover from the inital drop in numbers (see Figure 6) and are thinly spread across the area of interest. In places there are no predators at all which, in turn, allows prey to accumulate in "clouds" – see Figure 5. These clouds appear and disappear randomly depending on local predation and explain the large error bars that can be seen in the graph in Figure 6.

These experiments clearly show how animats evolve to suit a particular ecological niche. In the initial experiments, all predators began with a randomised rule set and then evolved to best fit into their environment. Successful predators in a resource-rich environment were those with rules such as Breed(B) and Eat(E) as top priorities in their rule sets (see Table 2). Predators in an environment with a lower grass value preferred rules such as Altruistic(L) and Seek Mate(M).

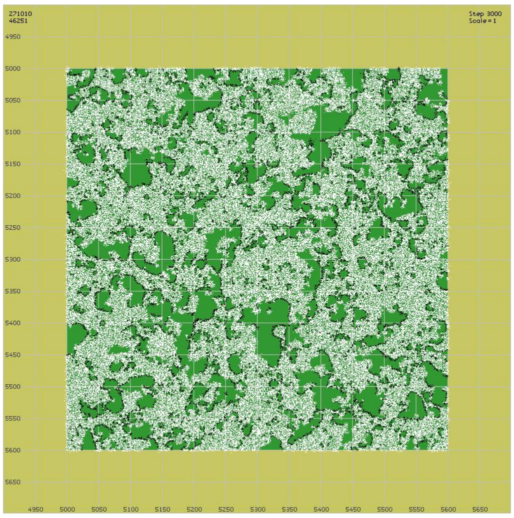

Figure 7: The situation after 3000 time steps with a good grass value of 60 where predators are black and prey are white. These predators originally evolved in a resource-sparse régime(grass value of 30) and thus eat less than "normal" predators and this, in turn, has led to a significant increase in prey – over 270,000 prey are visible in this diagram.

In particular, the predators that had evolved in the high-resorce environment were not able to survive when suddenly transferred to an environment with far fewer resources and rapidly died out (as demonstrated in Experiment 3). On the other hand, Experiment 4 showed that animats that had evolved to conserve resources (prey) continued this practice when transferred to a resource-rich environment, leading to an explosion in the prey population.

5 Summary and Conclusions

We have shown how our simple animat model can be used to explore spatially induced ecological niches, that emerge from chance and evolutionary fluctuations that occur in different spatial regions of the animat system.

Of the N possible animats subspecies that could arise in principle from the allowed rule priority sequence combinations, we have identified a subset which typically do survive as the most viable and successful.

In addition we have identified ecological niches whereby prey of one particular type creates an ecological niche where predators of another type survive and create an optimal dynamic equilibrium.

We believe these simulated evolutionary mechanisms show very interesting similarities with observations from real biological systems.

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