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Animat Swarms and their Role in Arterial Blockage Phenomena

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Swarms of microscopic organisms are well known in nature and have been shown to exhibit many unexpected collective behaviours. We model a swarm of artificial animats in a model where microscopic predator prey behaviours give rise to emergent macroscopic spatial phenomena. Animats with very simple local rules can be shown to exhibit a collective swarm response that can potentially be linked to some macroscopic task. We investigate microscopic instructions for a swarm of animats to affect the build up or removal of scale in arterial flow systems. We describe various ways to implement swarming in the model and report on some preliminary results showing how blockage material can be transported by animats and the emergent spatial patterns that emerge.

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Technical Report CSTN-060

Animat Swarms and Spatial Emergence Phenomena

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Abstract

Swarms of microscopic organisms are well known in nature and have been shown to exhibit many unexpected collective behaviours. We model a swarm of artificial animats in a model where microscopic predator prey behaviours give rise to emergent macroscopic spatial phenomena. Animats with very simple local rules can be shown to exhibit a collective swarm response that can potentially be linked to some macroscopic task. We investigate microscopic instructions for a swarm of animats to affect the build up or removal of scale in arterial flow systems. We describe various ways to implement swarming in the model and report on some preliminary results showing how blockage material can be transported by animats and the emergent spatial patterns that emerge.

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1 Introduction

A number of biologically-inspired computing approaches such as swarm modelling and intelligent animat agent simulation have recently been identified as promising ways of explaining collective and emergent phenomena. Emergence as a concept [1, 2] remains elusive to define precisely but is widely agreed to denote some sort of macroscopic phenomena that is not anticipated solely from the microscopic model details and input parameters of a model system.

Swarm-based system models are finding uses in exploring phenomena such as wall-building [3] as well as other biological phenomena such as flocking and herding [4]. These models give some quite deep insights into the behaviour of individuals as parts of swarms and other collectives. In addition to explaining - and removing some of the surprise - from the collective behaviour patterns that emerge, they also suggest ways of adjusting the behaviours of individuals to obtain particular collective outcomes. This latter is one of the goals of swarm engineering [5, 6]. It is attractive to be able to design the properties of an individual robot or nano organism and so attain the performance of a particular complex task by a large group of individually identical such components.

We have developed a spatial animat model, loosely based on the concept of predator and prey software agents that coexist in a simulated flat landscape. While several so-called animat models have been developed by researchers, our model is unique in that it makes use of a relatively large number ($\approx 10^5 - 10^6$) of very simple individual animats.

We are able to adjust the microscopic behavioural rules of our animats quite simply and have obtained surprising results over recent years including complex spatially emergent patterns such as spiral battlefronts [7]; spontaneous tribal segregation [8]; and ecologically relevant resource scarcity controlled migratory patterns [9]. Our motivation for the development of this model is primarily as a platform for exploring complexity and complex systems phenomena in a statistical sense, but it has been possible to explore some specific phenomena such as those shown by real predator-prey systems [10].

In this present paper we explore uses of simulation models for studying swarms or flocks of animats that carry out some specific and well-defined task such as moving material around a spatial environment. We have introduced material tokens into our animat model so that the normal collective spatial behaviour of the individual interacting animats can be exploited to set up particular patterns of the material tokens in a dynamical system.

Swarm models have been successfully investigated for a number of purposes including: automaton glider phenomena [11]; particle systems [12] and fluid flow such as vortex modelling [13]. However, it is not trivial to solve the reverse engineering swarm problem - namely how to design a microscopic agent that when duplicated in a swarm collective will cooperate with its peers to carry out a predefined task.

As an approach to this general problem, we consider how a swarm of animats might service a wall or boundary, keeping it clear of build up, or even repairing it in some sense. Figure 1 shows a speculative situation - asking the question as to whether we can design animats that will move randomly located material into desired macroscopic patterns or must we simply search for the right accidental combination of microscopic parameters?

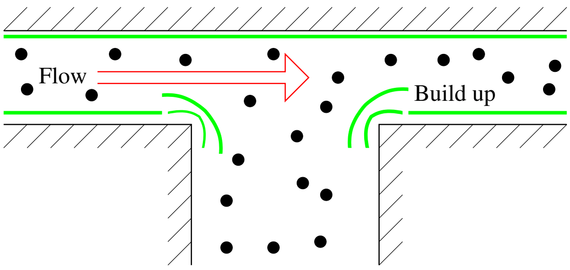

Figure 1: Animat flow at a T-Junction. What will be deposition/scale build-up behaviour and can we engineer animats to de-scale the walls of an artery or other pipeline system?

In section 2 we describe the key features of our animat model. In section 3 we discuss how material tokens can be introduced into the system and how the animats can be adjusted to move them around in a micro-programmed manner. We present some preliminary results showing the emergent spatial patterns of animats and material tokens in section 4 and offer a discussion of future applications and some concluding remarks in section 5.

2 The Spatial 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 [14], 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 [15, 16].

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 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. Eventually, if at a particular time-step an animat has failed to execute any of its rules it is said to have executed its “NOP” no-operation or “do-nothing rule.” 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 [14].

Animat behaviour is thus influenced by their environment. Until recently we used a completely featureless spatially uniform environment. Animats would therefore only distinguish different spatial directions and so forth from the patterns of other animats they encountered. In the work described in this paper we explore the effect of using grass patterns as “directing corridors” to steer the animats along.

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.

Table 1 summarises the normal animat model rules.

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

Code	Action	Predator	Prey	Conditions
A	move Away	No	Yes	adjacent prey (new rule)
B	Breed	Yes	Yes	well-fed; adjacent mate; birth conditions
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 (new rule)
L	altruistic	Yes	No	adjacent needy predator (new rule)
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 conditions are discussed below.

of rules. The model also requires the following global constants for each species: maximum age; maximum health; vision range (used to locate other animats); and a crowding number (if more than this number of animats are adjacent then they are crowded). 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. For tracking purpose it is possible to record where the corpse lies in the model space. 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 Swarms Ferrying Tokens

The animats behave in a manner not incompatible with predictions of the spatial diffusive versions of the Lotka-Volterra equations. Overall the population exhibits relatively smooth boom-bust phenomena but individual regions of space exhibit wild fluctuations. The spatial patterns that emerge when animats cross space in herds and other patterns are of a highly complex nature, with interesting and non-trivial interactions observed between species.

In order to explore swarm task execution we introduced another rule behaviour into the model. Passive tokens of matter were introduced. In fact our model apparatus made it simplest to introduce these as a third species that has a single "do nothing" rule. Predators and prey however can be given extra rules that say to pick up or drop down these material tokens depending upon the spatial environment encountered. So for example animats could be programmed to pick up a token (unless they were already carrying one) whenever they encountered one. This leads to an expectation that a maximal amount of tokens will be picked up and will be on the move at once, since they will only be dropped by animats when they die. The tokens therefore pile up where animat corpses are most frequent.

Another variation is for animats to set down tokens when certain conditions are fulfilled. We explored for example what would happen when animats preferentially discarded tokens when wall conditions were encountered. We explain how the wall conditions were set up in the following section.

4 Selected Results

Predators and prey were initialised in one of our usual random starting pattern. Matter tokens were scattered randomly throughout the spatial space of the model. The configuration snapshots shown below indicate that the movement patterns of the interacting predators and prey with the new token rules incorporated, act to gather the matter up from its random distributions and to form aggregated clumps. This can be thought of as animats "clearing rocks from a meadow." in some sense.

Figure 2 shows a T-shaped channel of animats that has been initialised randomly. Predators are coloured **black**, prey are coloured **white** and the material tokens are **red**. The background grass is coloured **green** and can be seen to change tone in figures 3 (after 1400

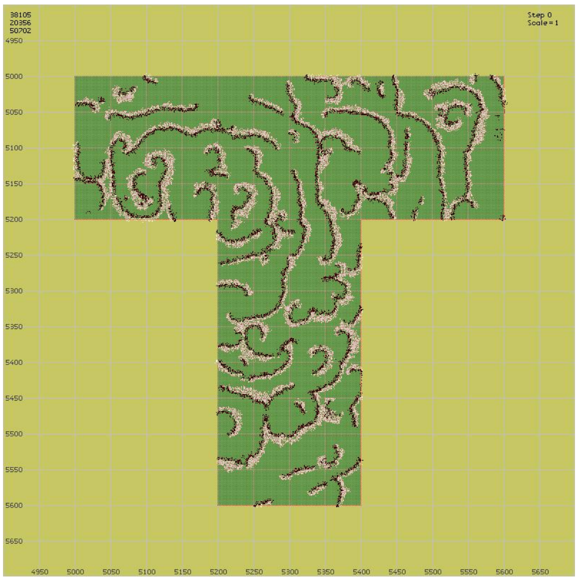

Figure 2: Step 300 showing how animats (white prey and black prey) have penetrated the whole space but are just beginning to gather red tokens which are still spread random uniformly amongst the green grass.

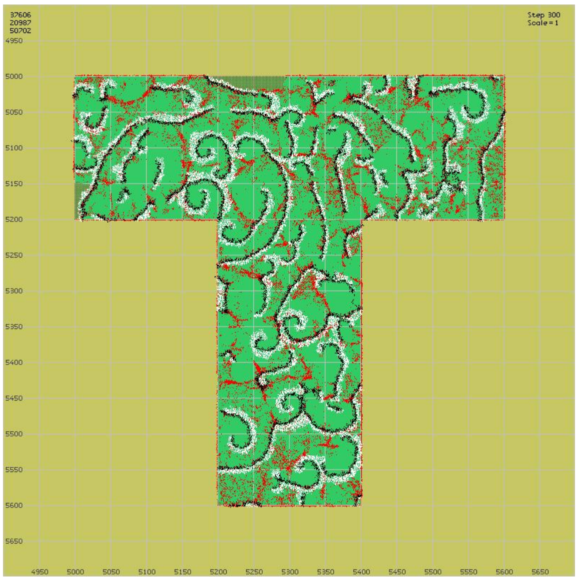

Figure 3: Step 1400 showing how tokens have already begun to be separated from the green grass and are being piled up.

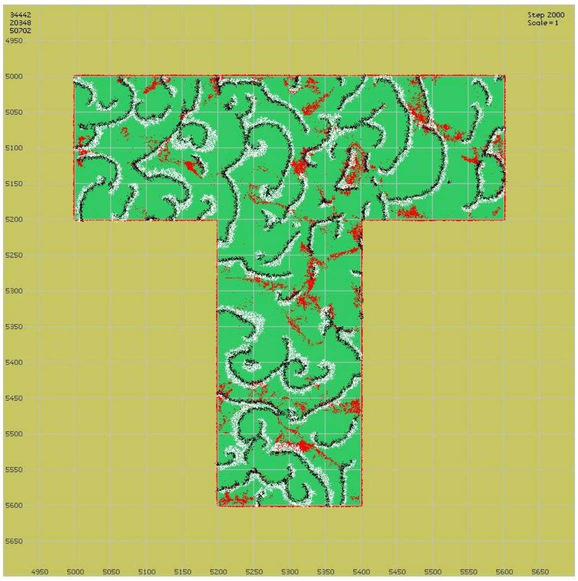

Figure 4: Step 2000 showing significant clumping of red tokens in a network of striations.

time steps) and 4 (after 2000 time steps). The initially randomly distributed red tokens which were mixed up with the green grass, have now been gathered together into spatial piles or clumps simply through the diffusive interaction of the warring animats.

The piles of token are not completely static - new animats can pick up tokens from the piles. However the tendency of animats is to put more tokens close together and this effect wins out. Over a long simulation time token piles gradually get moved together over several generations of animats. As described in [9] the sandy coloured regions are those where there is no grass. While prey animats can exist temporarily outside the grass region they will eventually die of starvation and consequently the grassed regions provide guiding corridors for both prey and of course for predators which cannot survive for long without prey. The configuration illustrations show one pixel per spatial grid square. So it is not unexpected that an animat which can live only a few tens of time-steps will not diffuse more than a few pixels into the starvation regions during its lifetime.

Figures 5, 6 and 7 show a directed corridor configuration set up to encourage the animat herd to diffuse in a clockwise direction. A grass richness gradient is applied so that while individual animats are hardly affected at all in their choices, statistically there is a small drift so that over many generations, the animats tend to diffuse clockwise. This is a good way to reveal what matter assembly patterns they leave behind them. As can be seen, the red matter tokens again start in a ran-

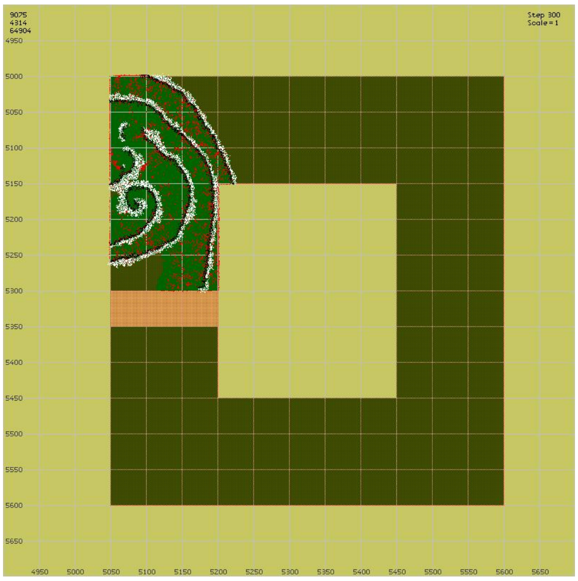

Figure 5: Step 300 - black predators, white prey start moving around red tokens which were initially randomly distributed.

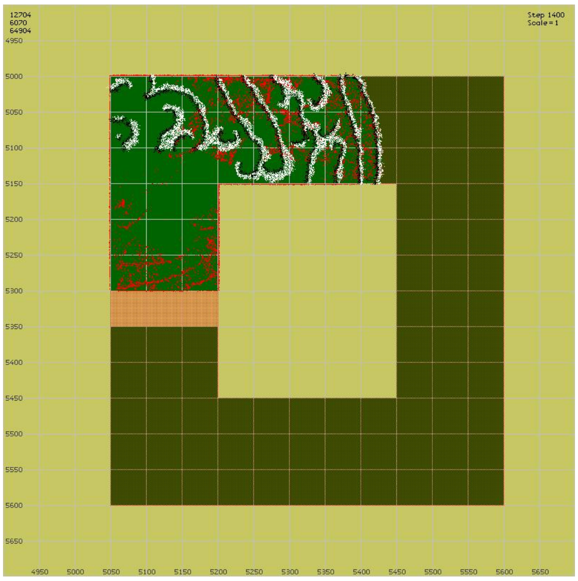

Figure 6: Step 1400 - over several generations black predators and white prey are diffusing as a herd, clockwise, while continuing to clump red tokens into deposits.

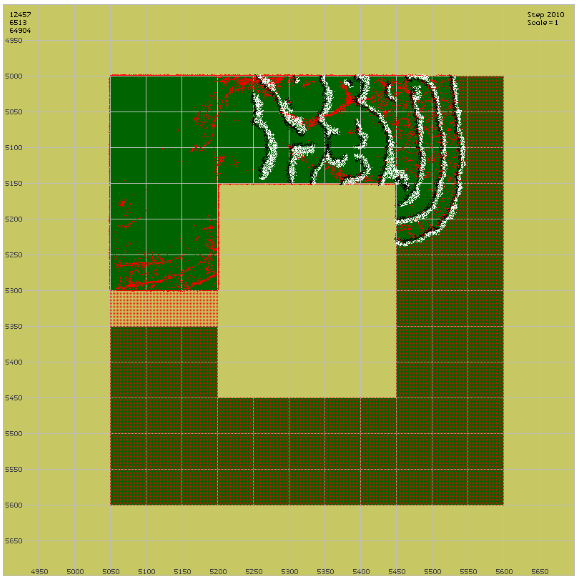

Figure 7: After 2010 time-steps the red tokens have been deposited into definite layers striated in the direction of diffusion, parallel to the direction of travel and the corridor walls.

dom pattern but are gradually piled into clumps by the animats. As the herd passes on it leaves behind striated patterns of tokens.

The red/green (dirty green) token/grass mixture is seen to be gradually cleansed of red tokens as the herd moves around the corridor. This effect is the one we anticipated in figure 1. Animats are reminiscent of cells or microorganisms flowing around pipe-like systems such as arteries. Through the course of their normal life cycles they might leave behind excreta or deposits on the walls that may take the form of layers, and which may eventually change or restrict the properties of the system as a whole.

5 Discussion and Conclusions

We have described our animat model based upon predator and prey spatial agents. We have shown how we can use regions of rich and scarce resources to channel animats to diffuse in preferential directions. We have also introduced the notion of a swarm task for they animat population as a whole to undertake. The particular experiments we present here showed how animats might gather scattered material together into piles or clumps that would be easier to subsequently harvest.

We have also considered how a third species might "prey upon the dead" acting as a garbage collector or scavenger. Bonabeau *et al.* have considered how ants organised their dead into emergent patterns [17]. We see in the simulations presented here a direct correlation between the location of corpses which are assumed to decay away into the environment leaving behind any carried tokens. We also experimented with an animat rule that would introduce a tendency for animats to discard a token if and when they were in vicinity of a wall. This experiment was somewhat inconclusive, with no obvious emergent patterns arising. We believe this is simply due to the tendency for animats to stay within the populated grassy regions and so relatively few tokens were ever deposited at the walls and those that were would be picked up again by passing animats at roughly the same probability. This effect emphasises the difficulty in addressing the reverse swarm engineering problem. It is still an open question as to how to choose microscopic animat properties to guarantee specific *a priori* swarm behaviours.

Our swarm behaviour arises from a set of very simple microscopic rules. We have not yet attempted to apply theoretical models to explain our findings, but we speculate that the energy minimisation methods that can be applied to particle swarms [18] might be applicable to systems such as ours. We believe microscopic animat models have great promise as a simulation test-bed for studying ideas such as swarming and other biologically inspired models of complexity and emergence.

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