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## Intelligent and Adaptive Animat Resource Trading

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# Intelligent and Adaptive Animat Resource Trading

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## Abstract

Trading of resources is an important sociological behaviour that is believed to be indicative of intelligent life forms, but which is non-trivial to model successfully. We have incorporated trading of resources that are critical to the survival of predator agents in a spatial predator-prey animat simulation model. We find that predator agents adapt to trade with one another in the face of extinction and that this leads to successful and stable dynamic equilibria between predators and prey. The spatial mixing properties of agents in our model system shift as a result of the trading patterns. We discuss these emergent phenomena and how they relate to microscopic model parameters and speculate as to how these ideas might be generalised to model trading patterns and markets.

**Keywords:** intelligent agents; trading; animats; emergence.

## 1 Introduction

Modelling resource trading amongst intelligent agents is a non-trivial problem [1, 2] and despite a number of agent simulations on computational grid systems [3, 4] and multi-agent systems [5, 6] it is not a simple matter to establish a framework and environment where agents can be shown to quantitatively benefit from trading. An artificial life model provides a possible framework for exploring trading, since intuitively cooperation and resource exchange might manifest themselves as improvements in the success and efficiency of artificial life agents.

Several Artificial Life simulation models exist, including [7–9]. These concentrate almost exclusively on the evolution of “digital organisms” and the corresponding

emergent macro behaviours. They are not particularly concerned with the details of the lives of individual “animats” [10]. One exception is [11] where a hierarchy of animats is established in which beetles need to eat worms and worms need to eat grass. However, this model does not study animat evolution and behaviour but focuses on the conservation and transfer of energy.

Our predator prey model [12, 13] has been refined over a period of several years. 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 [14]. Typical emergent formations can be seen in Figure 1.

Few Artificial Life models have been used to study the effects of “higher-order” interactions such as altruism and trading. We have carried out one study of altruistic behaviour [15] that strongly suggests that altruism can evolve naturally and provides benefits for altruistic groups. In this article, we study trading among animats and attempt to find situations in which trading can benefit both the individual and the group.

A brief overview of the model is provided in section 2. We then modified the model to include two different types of prey (discussed in section 3) and changed the predators so that they were required to consume prey of both types to survive – see section 4. We were then able to conduct some experiments to compare predators that traded resources with those that did not. These experiments are described in section 5. Finally, we suggest some areas for further study in section 6.



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. Note how the animats exist almost exclusively on the grassed area.

## 2 The Animat Model

Our model contains two species of “animat” – the predators and the prey – existing on an unbounded plain. Each animat has a set of rules associated with it and at every time-step, the animat executes one of these rules. A rule often has conditions that must be satisfied before it can be executed. The rule sets used for the experiments described here were as follows:

Rules for predators:

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:

1. breed if health  $> 50\%$  and mate adjacent
2. eat grass if health  $< 50\%$  and not overcrowded
3. seek mate if health  $> 50\%$
4. move away from other prey if health  $< 50\%$

5. move away from adjacent predator
6. randomly move to adjacent position

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. Future work could be the inclusion of mutation operators to produce genetic effects. Thus far 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. It is interesting to note that prey rule 5 (flee from predators) was regarded as very important in the original model but experiments [12] have shown that this rule is not particularly important and it has thus been accorded a low priority.

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 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. During the experiments described here the birth rates were modified as discussed below.

Predators need to consume prey and prey need to eat grass to survive. Every animat maintains a “current health” value. Each time step this value is reduced and if it reaches zero the animat “starves to death”. Whenever the animat successfully executes the “eat” rule, the 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 [16] we have demonstrated that these limitations do not affect the emergent macro 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 [14]. 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 over 250,000 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 Two Types of Prey

In order to facilitate trading, we modified the model to contain two different types of prey. During the initialisation phase of the simulation, each prey animat receives a marker identifying it as “Type A” or “Type B”. There are equal numbers of Type A and Type B markers and they are randomly allocated. The markers are noticeable only to the predators – the prey animats themselves remain oblivious to the differences between them. Thus prey behaviour in the simulation remains unchanged.

When a new animat is “born” it takes on the marker of its mother. However, previous work [17] has shown that this method of propagating markers leads to the animats forming distinct clusters of each marker type. For the experiments described below it was important that the prey did not cluster according to marker because this would make it extremely difficult for predators to have access to both types of prey and thus would cause a rapid drop in predator numbers, probably leading to extinction of the species. We therefore modified the inheritance rule as follows:

*When a new animat is born there is a 90% chance that it inherits the marker of its mother and a 10% chance that it takes on the other marker.*

This chance of mutation ensures that the prey remain mixed enough to allow predators access to both types. In [17] we found that the animats segregated into tribes and that therefore the only location predators could survive would be at the boundaries between tribes. The well-mixed prey system is both more interesting and stable.

## 4 Predators Requiring two Food Types

We then modified the predators in the model so that each predator required a supply of both prey types to survive. In the original model, each predator was supplied with a “current health value” which was decreased every time step (possibly causing “death by starvation”) and increased every time the predator consumed prey. Now the predators are required to maintain three current health values as follows:

- Health-A is increased every time the predator eats a Type A prey animat and is decreased every time step;
- Health-B is increased every time the predator eats a Type B prey animat and is decreased every time step;
- Health is the *minimum* of Health-A and Health-B and is used for all conditions involving health, e.g. breeding, seeking prey, “starving to death”, etc.

Thus health plays the same role that it always has in the model but it is now calculated differently – instead of increasing each time the predator consumes prey it is now always the minimum of Health-A and Health-B.

This change to the predators caused an enormous difference in the various macro-behaviours in the model. In particular life became far more difficult for predators causing many of them to die out. Due to the lack of predators, the prey population expanded greatly. It became necessary to modify the birth rates in order to assist the predators and reduce the numbers of prey. The birth rate for predators was increased from 15% to 20% and the birth rate for prey was reduced from 40% to 20%.

Figure 2 shows the situation during a typical run of the modified model. The predators are struggling to meet the new conditions imposed on them and have been greatly reduced. This reduction of predators has, in turn, caused a dramatic increase in the prey population which is now over 286,000.

## 5 Trading Predators

Predators were now modified in order to allow them to trade one type of health for another. If a predator is low on Type A health it is assumed to be prepared to trade Type B health in order to obtain Type A health, and

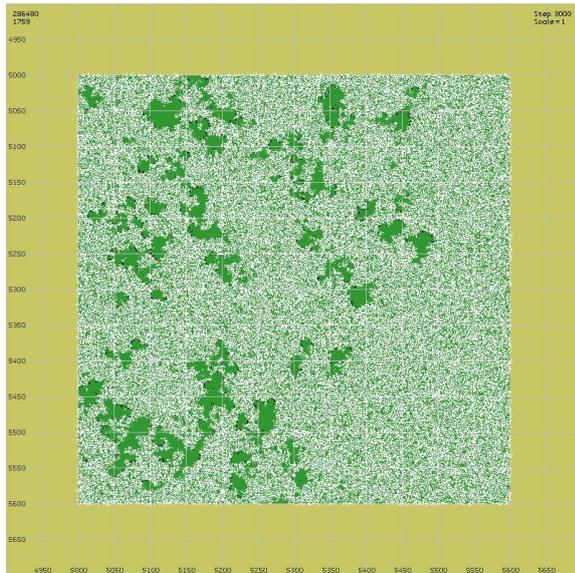


Figure 2: The situation at step 3000 for a run of the modified model in which two types of prey exist and predators have to consume both types to survive. Predators are black and prey are white. Predators are clearly struggling to meet these constraints and are reduced in number with a corresponding increase in the number of prey.

*vice versa.* In order to consider trading the predator must have another predator as an immediate neighbour. This predator is called “neighbour” in the following algorithm that defines the trading process.

1. if Health-A is less than Health-B then the predator is designated as a “Seller-of-B”.
2. if Health-B is less than Health-A then the predator is designated as a “Seller-of-A”.
3. if neighbour’s Health-A is less than Health-B then the neighbour is designated as a “Buyer-of-A”.
4. if neighbour’s Health-B is less than Health-A then the neighbour is designated as a “Buyer-of-B”.
5. only proceed if the predator is a “Seller of X” and the neighbour is a “Buyer-of-X”...
6. difference one is the difference between the predator’s health levels.
7. difference two is the difference between the neighbour’s health levels.
8. the final amount is set to the minimum of difference one and difference two.

9. the final amount of the appropriate health type is transferred between the two predators.

Figure 3 illustrates this procedure. It is important to note that this procedure can be defined as “trading” because animats exchange equal amounts of resources. This is different from previous experiments (see [15]) which investigated “altruism” which occurs when one animat donates resources to another with no reward.

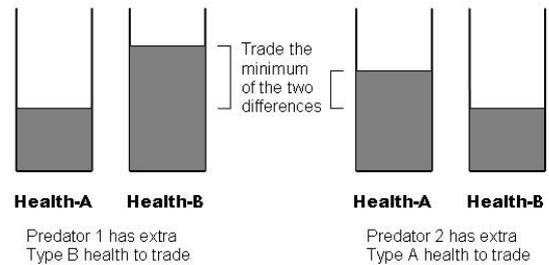


Figure 3: An illustration of how trading takes place between predators. Predator 1 requires more Type A health, Predator 2 requires more Type B health and both predators are able to provide the other type in exchange. Each predator will trade a maximum equal to the difference between the two health levels. The actual amount traded is set at the minimum possible trade.

Figure 4 shows the situation at time step 3000 of a run in which predators are trading. The predators are doing considerably better than before (see Figure 2). There are still large numbers of prey but not as many as shown in Figure 2 when predators were not able to trade.

The results of this experiment are shown in Figure 5 and clearly demonstrate the advantages of trading which assist both individual animats and the whole community.

## 6 Discussion and Further Work

The experiments reported here show that trading gives the predators an advantage over non-trading ones. It also leads to a higher possible stable point for the prey population than would otherwise occur.

However, individual spatial regions can and do fluctuate considerably in population activity. The model normally manifests this effect as a combined set of periodic-boom bust cycles in the regions that when combined over all into a figure for the population overall display a relatively even periodic boom-bust signal. This itself is super-posed on slowly changing envelope functions that indicate the general level of success or stability of

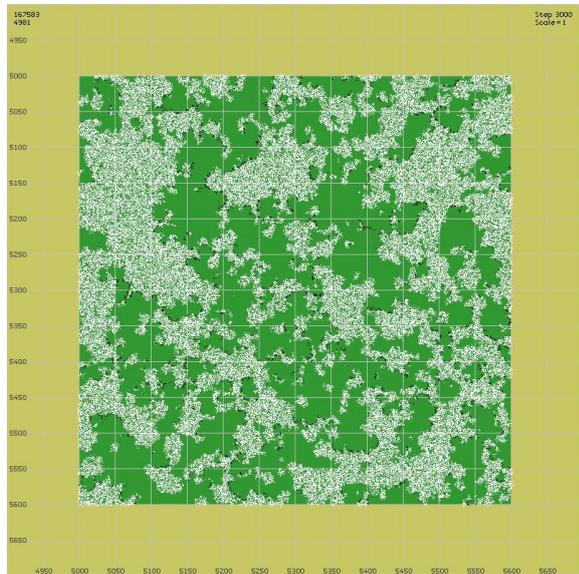


Figure 4: The situation at step 3000 for a modified model in which two types of prey exist and predators have to consume both types to survive. Predators are black and prey are white. Predators can now trade with other predators and have thereby noticeably improved their situation from that depicted in Figure 2.

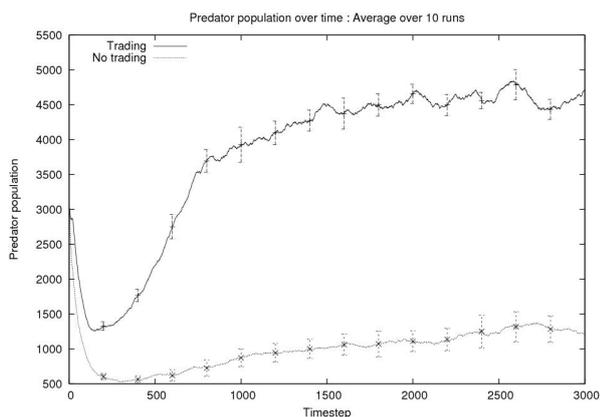


Figure 5: This graph shows how the predator population is significantly higher when predators trade. All population figures in this graph are averages over ten different runs.

the animat populations. In the case of figure 5 the envelopes are slowly growing curves that flatten out as the model landscape reaches its preferred supported population.

Our model framework is quite stable against different starting conditions - at least in a statistical sense. The population data shown in figure 5 was based on an average over ten independent runs (and independently chosen starting conditions.)

There are a number of possible extensions to the model presented here. We are considering how evolutionary behaviour can be incorporated into the model using a carefully controlled set of crossover and mutation operations between subspecies within a main species (predators or prey). We believe it might be possible to allow a mix of different predators to compete in the same system and to evolve a preference for trading behaviour.

In our present model all animats only communicate behaviours over very short distances. As we have observed it is possible to contrive global parameters so that prey divide into well defined tribal regions and local shortages of a particular prey type can be engineered. Arranging some predators to live long enough to travel over long distances and arranging some means for them to communicate over longer distances, would create the fascinating opportunity for specialist trader animats to develop.

A final development we are considering concerns embodying resource value as some commodity independent of the health and life cycle of individual animats. Trading via an exchange of tokens or some other permanent store of wealth also opens up some interesting sociological modelling scenarios including monopolies, and other practices that would drastically change the fitness landscape of the model [18].

## 7 Summary and Conclusions

We have described our animat agent model that is based upon a large set of spatially positioned predator-prey intelligent agents. We have incorporated the notion of two distinct prey species which are both essential to the health and survival of prey animats. In a well-mixed environment we have shown that it is advantageous to prey to trade the two different sorts of prey in order to survive, given that an individual microscopic predator animat may not have immediate access to both sorts of prey in its environment.

We have shown how the system where predators trade is much more successful in terms of the number of sup-

ported animats in the population and also in terms of better management or husbandry of the herds of prey.

The key component in our model was establishing a simple and quantifiable trading exchange mechanism that makes natural use of the spatially mixed and dynamical nature of the system. The fact that our animats diffuse around and have a finite lifetime aids the market mixing and prevents it becoming stuck in anomalous cycles.

We believe our model framework has promise for investigating more generalised trading scenarios, such as multiple commodity markets and regions of local scarcity of one commodity that therefore offer long ranging traveling animats interesting opportunities for arbitrage. It is not yet clear how our animats should accumulate profit across generations, although we are presently considering some form of stored resource that can be modelled as a commodity in our model framework.

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