Modelling Predator Camouflage Behaviour and Tradeoffs in an Agent-Based Animat Model

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Many real animals employ camouflage using either their natural appearance or by adapting their behaviour. We explore the effect on large scale animat agent populations when camouflage behaviour is an available option for predators. We find that individuals who adopt this behaviour are relatively successful in obtaining prey and thus prolonging their lives against threat of dying of hunger. Consequently in our simulation model predators have a longer life and a greater statistical chance of passing on this trait. However there is an interesting consequence for the overall system, whereby over successful predation drives the coupled system of predators and prey downwards to a lower population levels than without the camouflage trait.

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Modelling Animat Camouflage Behaviour and Tradeoffs between Individual Survivability and System Population Health

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ABSTRACT

Many real animals employ camouflage using either their natural appearance or by adapting their behaviour. We explore the effect on large scale animat agent populations when camouflage behaviour is an available option for predators. We find that individuals who adopt this behaviour are relatively successful in obtaining prey and thus prolonging their lives against threat of dying of hunger. Consequently in our simulation model predators have a longer life and a greater statistical chance of passing on this trait. However there is an interesting consequence for the overall system, whereby over successful predation drives the coupled system of predators and prey downwards to a lower population levels than without the camouflage trait.

KEY WORDS

agent-based model; animat; camouflage; predation; carrying capacity.

1 Introduction

Agent-based models continue to stimulate research across a range of areas. Some of these models focus on society and human behaviour such as crowds and collective decision making [1], simulations of combat [2] and financial market systems [3], whereas others focus on the simulation of virtual animals or "animats" [4, 5] such as flocking [6] and communication [7].

This article is positioned in the latter category and builds on a well-established spatial predator-prey model [8]. The model consists of a featureless plain on which large numbers of animats reproduce, feed, flee predators or hunt prey and eventually die. The model reproduces the repetitive cycle of behaviour that is well known from predator-prey equation-based models such as the Lotka-Volterra equations [9]. Predators kill prey and, if prey is plentiful, the predator numbers in-
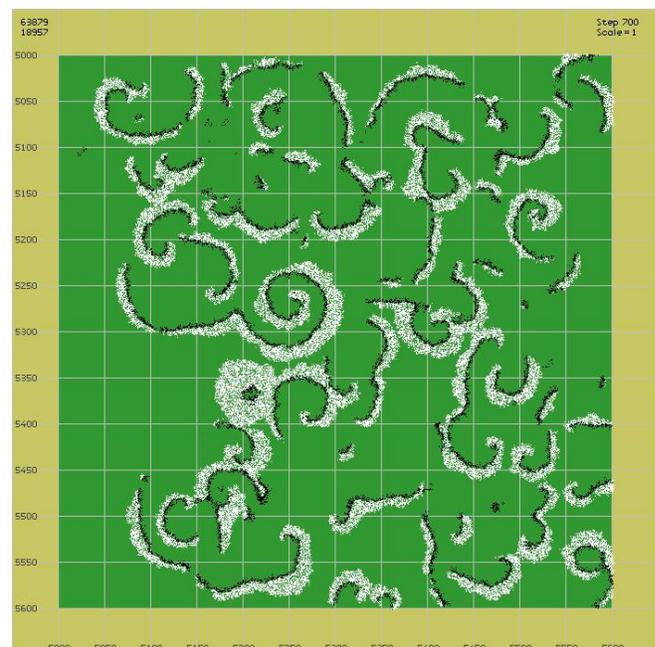

Figure 1: The situation at step 900 of a typical run showing animats on a square grassed area. Predators are black and prey are white. Various macro-clusters, including spiral formations, have emerged. This screen shot contains 12,870 predators and 73,605 prey animats.

crease, leading to an increased demand for prey which causes the prey population to drop and this in turn causes a drop in the predator population which allows the prey population to recover, and so the cycle continues.

Virtual worlds modelling predator-prey systems are well covered in the literature [10–14]. A common attribute of all these models is the ability to reproduce [15] and thus propagate the species. All agent-based models include an analysis of "emergence" – the complex and often unexplained patterns

and clusters that emerge from the interactions of many agents at the local level. In predator-prey models, emergence can take the form of the defensive spirals and other features discussed in [16] and shown in Figure 1.

However, most of the early models adopted a rather crude approach to reproduction, namely at a certain instant in time an animat produces a fully-functioning copy of itself – albeit with some modification to internal rule structures via mutation and/or cross-over as discussed in [17,18]. The model described here has already been refined considerably and now incorporates the feature of gestation. This considerably alters animat behaviour as it is now much more important for "pregnant" prey to evade predators in order to reproduce later This, in turn, alters the priority order of the rule-set for prey animats with the rule "flee from predator" becoming the top priority. These phenomena are discussed in detail in [19].

This article continues to explore the changes to the model caused by the introduction of gestation. Since flight from predators has become a top priority for prey, it is reasonable to assume that predators may evolve some technique for making it easier for them to catch prey. One well-known technique is predator camouflage. A good overview can be found in [20] and more can be found in [21].

Our simulation model of course abstracts over the exact mechanisms for such traits to evolve or appear. The animat model we use has a large enough population that we can study such effects from a statistical perspective over several generations. Observations are therefore insensitive to microscopic implementation details on how such behaviour would actually be passed on in real biological systems. We present results on introducing: a fixed camouflage trait; evolution of camouflage as a fixed trait or as a variable ability into populations.

In this paper we investigate the effect on both predator and prey populations, and thus on the carrying capacity of the system as a whole, when predators make use of camouflage. A brief overview of the predator-prey model is provided in Section 2. The introduction of fixed and identical camouflage for all predators is discussed in Section 3. Section 4 allows predators to evolve their own camouflage levels starting from a very low level. Section 5 is similar but starts all predators at a very high level of camouflage, with the possibility of evolving changes to the camouflage level. We discuss the implications of traits like camouflage on the overall system in Section 6 and offer some conclusions and ideas for future work in Section 7.

2 The Predator-Prey Animat Model

It is valuable to have a well-explored model framework into which a new behaviour can be injected to test its microscopic effect and macroscopic influence. We summarise our predator-prey animat simulation framework before describing how the camouflage behaviour was incorporated.

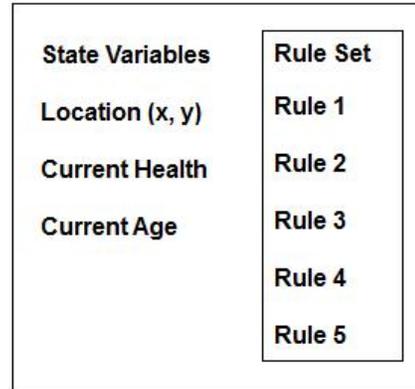The simulation system and model we use for this work is

Figure 2: Each animat maintains state variables and a set of rules. The rules differ depending on species (prey or predator) and sometimes differ within a species, e.g. different prey animats may give a different priority to the "flee" rule.

based on a spatial collection of individual finite state machine animat agents [22]. Each of these agents acts as either predator or prey and this adversarial mechanism enables selection and adaptation of individual sub-species according to the prevailing macroscopic conditions within the simulated model system. Input from its immediate spatial neighbourhood is provided to each animat machine, with a stochastic mechanism is used to deal with tie-breaks or animat rule conflicts.

This predator-prey model [8] has been developed and refined over nearly a decade of work and it locates hundreds of thousands of animats on a two-dimensional featureless spatial plain. There are two main species of animat – the predators that need to eat prey to survive and the prey that "graze" (eat grass). For these experiments, the grass was placed evenly in a large square area covering most of the map. Prey do not survive for long away from the grassed area and hence both prey and predators (that require nearby prey) are effectively restricted to the grassed square, although individual animats do sometimes move outside the area. The grass is thus just a useful mechanism to bound the model and prevent uncontrolled population explosion into unbounded space. In this present paper we introduce an additional trait - camouflage - that predators have and we therefore have subspecies of predators - those with and without a camouflage mechanism or behavioural trait.

Our individual animats are each implemented as an instance of the animat class which maintains a set of state variables (location, health, age) and a set of rules – see Figure 2.

At every time step of the model the age of an animat is incremented and if it reaches the pre-defined maximum for the species the animat "dies of old age" and is removed from the system. In addition, at each time step the health of every animat is reduced and if it reaches zero then that animat "starves to death" and is also removed from the system. An animat's health can be increased by eating (predators eat prey and prey

eat "grass"). However health may not be increased above a pre-defined maximum for each species.

Every animat carries a small set of rules that direct its microscopic behaviour and at each time-step of the simulation, each animat executes one of these rules, causing it to: move; eat; or breed. The rule set in fact defines the species or sub species of animat. The interacting directed movements of thousands of animats produces emergent clusters and formations that have been previously analysed [23]. The rule sets differ for each species (predator and prey) and can also be set up to differ for sub-species within species, if required. Section 3 describes a set of experiments in which groups of prey animats have different rule sets. If it is not stated otherwise, each animat is identical to all other animats of its species.

The rule set of every animat lists the rules in *list priority order*. Thus every animat, at every time-step, always attempts to execute rule 1. However, most rules are conditional on certain requirements being met, for example a certain rule may only be executed if another animat is adjacent. If the conditions for a rule cannot be met, then that rule is ignored and the animat will attempt to execute the next rule in the set and so forth until a rule succeeds. The rule sets for both species are listed in Table 1. Animats always have some rule such as "do nothing" or "move" that will succeed.

Table 1: Animat Rule Sets in Priority Order

Rules for predator animats:	Rules for prey animats:
1. breed if health > 50% and mate adjacent	1. graze (eat grass) if health < 50%
2. eat prey if health < 50% and prey adjacent	2. breed if health > 50% and mate adjacent
3. seek mate if health > 50%	3. randomly move to any adjacent position (50% chance of success)
4. seek prey if health < 50%	4. seek mate if health > 50%
5. randomly move to any adjacent position (50% chance of success)	5. flee from predator if predator is adjacent

The "breed" rule is used to create new animats. For these experiments, a new animat is always a clone of its parent (identical rule set) and is placed adjacent to the parent when it appears. In previous versions of the model the new animat was created at the time of execution of the breed rule. This is consistent with other Artificial Life models as discussed above.

In the following sections, we alter the breeding rule mechanism to incorporate a time delay – or gestation period – between an animat breeding and giving birth. This can be done in a number of ways, as described below.

FILL IN THIS EXTRA BIT... The camouflage behaviour can be incorporated into the model in a number of ways...

3   Experiment 1 – Fixed Camouflage Values

A simple way to start exploring the role camouflage plays is to set up predator animats that have a camouflage effectiveness which can be implemented as a simple stochastic mechanism whereby it affects that predator's chance of remaining undetected as it closes in upon prey.
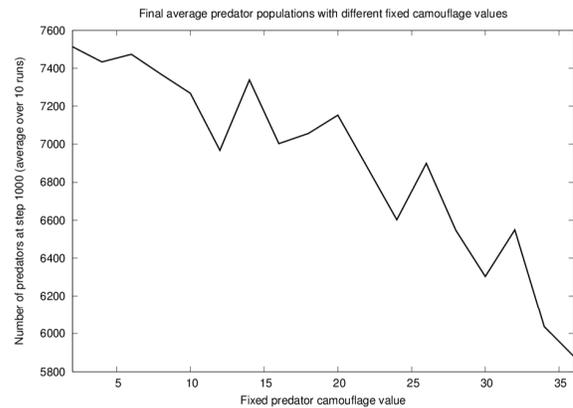

Figure 3: Plot showing the effects of fixed predator camouflage values on predator populations. As camouflage becomes more effective, predators catch more prey causing the prey population to fall and in turn making it difficult for predators to find more prey. The predator population thus also declines.
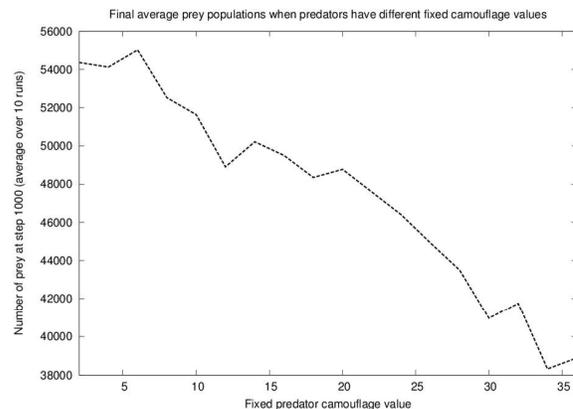

Figure 4: Plot showing the effects of fixed predator camouflage values on prey populations. As camouflage becomes more effective, predators catch more prey causing the prey population to fall.

In this first series of experiments, predator camouflage was introduced into the model in the following way: each predator agent was assigned a "camouflage value" which is an integer

value in the range 1 to 99. The camouflage value is the percentage chance that the predator will remain undetected by prey. Hence there is a 99% chance that prey will detect a predator with a camouflage level of 1, there is a 30% chance that prey will detect a predator with a camouflage level of 70, and so on.

At the start of a simulation, all predators receive the same camouflage value. The model can then be run in one of two ways: either every predator always carries the initial camouflage value, i.e. all predators are clones of the initial predators; or the camouflage level is allowed to mutate and evolve from one generation to the next.

In this experiment, only the initial camouflage values were used (all predators were identical clones). This enabled an analysis of the effect on both prey and predator populations of a camouflage value that was fixed across the predator population. Several fixed camouflage values were tested and the results are shown in Figure 3 and Figure 4. Each data point in the graphs is the final population figure at the end of a simulation of 1,000 time steps during which all predators carried the designated camouflage value. These population values were averaged across ten runs with different random number seeds.

An unexpected outcome of this analysis is that the predator population clearly does not benefit from increasing the camouflage value, although increased camouflage values do assist individual predators to catch more prey. As individual predators become more successful at catching prey, the prey population declines. This in turn, increases the difficulty for predators to find more prey and hence increased camouflage does not benefit the predator population as a whole.

Figures 3 and 4 both show a steady decline in population overall. It is expected d that the variations would smooth out if a larger number of separate runs were incorporated into the averages. Note that the numbers of prey are always larger than the predators. Predators consume around seven or eight prey during a typical lifetime in the normal course of the model. This means that any individual predators that live significantly longer and therefore consume significantly more than their normal "share" are disadvantaging the remaining predators as well as risking over-hunting the prey which leads to the well known boom-bust cyclic population phenomena [24].

4 Experiment 2 – Evolving Camouflage

A second approach to introducing camouflage and watching it spread was used in this series of experiments.

Experiment 1 in section 3 established that different (fixed) predator camouflage values affected both the predator and prey populations. The experiment (number 2) described in this present section was designed to enable the predator population to evolve the most efficient camouflage value.
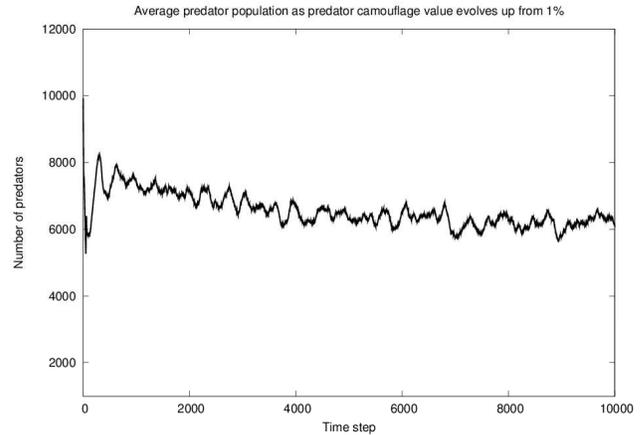

Figure 5: Plot showing the effect on predator population as predator camouflage values are allowed to evolve naturally over time. All predators were initially allocated a camouflage value of 1%. The plot shows the average populations over ten runs with different random number seeds.

In this experiment, all predators were initially assigned a camouflage value of 1% but camouflage values were allowed to evolve due to mutation. When a new predator is produced, it inherits the camouflage value of its parent but makes a random change to the camouflage value (mutation). This change can be as much as 5% more or less than the inherited camouflage value. For example, if an existing predator has a camouflage value of 25% its offspring can have camouflage values anywhere in the range from 20% up to 30%. However, camouflage values are restricted to a minimum of 1% and a maximum of 99%.

Figure 5 and Figure 6 show the average populations of predators and prey respectively over time as the camouflage values mutate and evolve within the predator population. It can be seen that both predator and prey populations decline initially but then become stable at about 10,000 steps.

Figure 5 and 6 show the characteristic set of rapid temporal fluctuations around a more slowly changing envelope - in this case an exponential decay towards a mean population value for both predators and prey. As in experiment 1, there is also a ratio of approximately 7:1 for prey to predators reflecting the prey consumed by a typical predator during its simulated lifetime.

Figure 7 shows the change in average predator camouflage value over time. Camouflage values initially climb rapidly as individual predators mutate to a higher camouflage value, enabling them to more easily catch prey and thereby survive to produce more offspring. However, as the prey population declines, the benefits of camouflage are no longer as important to survival and it can be seen that the camouflage value stops increasing and does not change significantly from step 3,000 to step 10,000. It is interesting to note that the camouflage value never moves much above 30% even though the
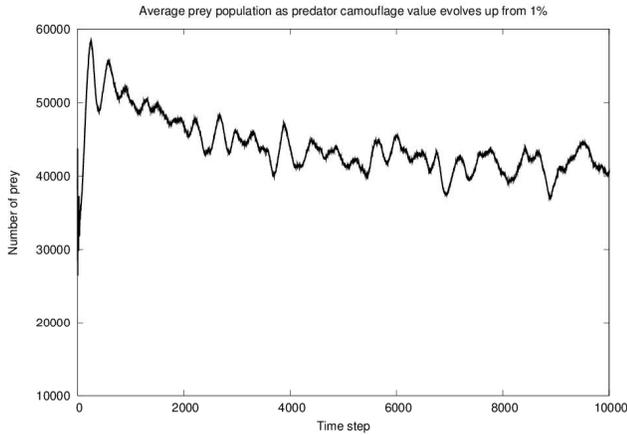
Figure 6: Plot showing the effect on prey population as predator camouflage values are allowed to evolve naturally over time. All predators were initially allocated a camouflage value of 1%. The plot shows the average populations over ten runs with different random number seeds.

maximum possible value is 99%.

It remains to be seen whether this men value of $25 \pm 5\%$ is a universal one or if it is affected by other global parameters such as grass abundance and so forth - which we kept fixed for the work reported in this present article.

The fluctuations are associated with spatial fluctuation in a particular model run and it is expected that this plot would smooth out considerably if averaged over many more separately seeded runs. The trend appears to be a rise then slow equilibration towards a steady value that in some sense characterises the prevailing conditions within the system as a whole.

5 Experiment 3 – Downward Evolution

A third series of experiments was established to investigate how the overall system would adapt to camouflage traits and how it might drive them.

This experiment was similar to that described in Section 4. However, instead of starting with an initial predator camouflage value of 1%, this experiment started with a uniform camouflage value of 80%. It would seem reasonable to assume that, as the predators have a very high camouflage value at the start, they would retain this high value as it makes individuals more effective at catching prey. However the results show that evolution and mutation drive the camouflage value down significantly.

The process of mutation is identical to that described in Section 4. Thus when a new predator is produced, it inherits the camouflage value of its parent but makes a random change to the camouflage value (mutation). This change can be as
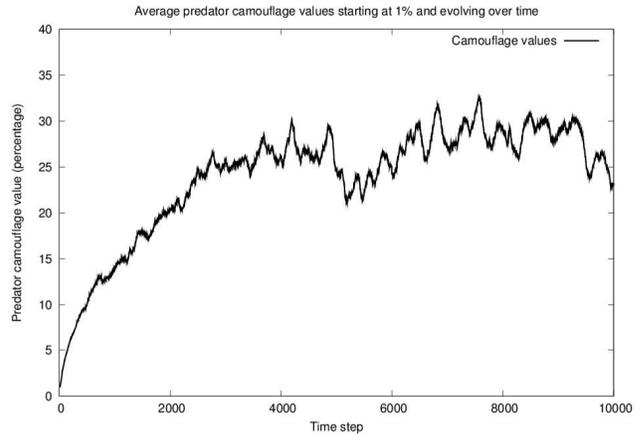

Figure 7: Plot showing how the predator camouflage values evolved over the simulations shown in Figure 5 and Figure 6.

much as 5% more or less than the inherited camouflage value. For example, if an existing predator has a camouflage value of 25% its offspring can have camouflage values anywhere in the range from 20% up to 30%. However, camouflage values are restricted to a minimum of 1% and a maximum of 99%.

Figure 8 and Figure 9 show the average populations of predators and prey respectively over time as the camouflage values mutate and evolve within the predator population. It can be clearly seen that the initial extremely high predator camouflage value of 80% leads to a significant increase in the predator population along with a major fall in the prey population.

Figure 10 shows the change in average predator camouflage value over time. Due to the initial success of the predators, there is a significant fall in the prey population. Ironically, this often leaves the most successful predators (with a high camouflage value) in an area which becomes denuded of prey. This means that the predators that are able to survive and reproduce are those where mutation is rapidly driving their camouflage value downwards. Predators only survive as a group when their camouflage is **less** effective. The results clearly show a rapid decline in the average camouflage value from the initial 80% to somewhere in the range from 20% to 30%. The predator-prey balance can only be sustained when predators carry this lower level of camouflage value.

The fluctuations again are linked to spatial variations and would smooth out when averaged over more independent model runs. The trend from Figure 10 is to a falling characteristic camouflage effectiveness, a small undershot then a gradual equilibration to a long term mean value about which the system oscillates. In the work reported here we have run the model for 10,000 steps. This is computationally expensive but was justified for the phenomena observed. In other prior work many of the temporal effects occurred in less than 1,000 or 2,000 steps. Propagation of the mutated/evolved camouflage effectiveness seems to be somewhat slower than
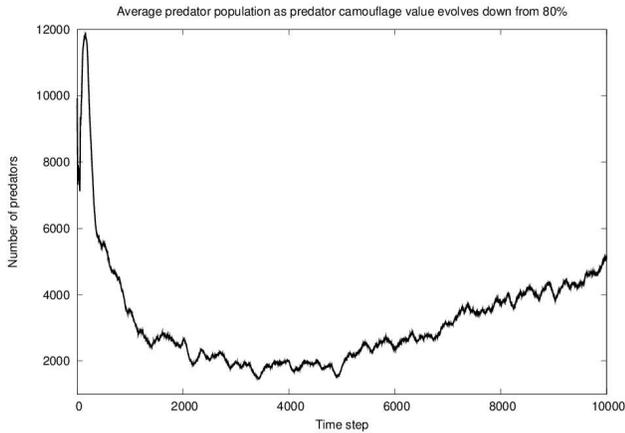
Figure 8: Plot showing the effect on predator population as predator camouflage values are allowed to evolve naturally over time. All predators were initially allocated a camouflage value of 80%. The plot shows the average populations over ten runs with different random number seeds.

this however.

6 Discussion

We have observed a classic systems effect, whereby a trait or property that is good for individuals does not benefit - or at least has a counterintuitive effect on - the overall system. A system where predator agents develop a trait that allows them to survive drives out less successful predators, but also leads to over consumption of prey and hence a crash in the carrying capacity of the system as a whole.

While our model is obviously a highly simplified one with microscopically minimal behaviour rules, it does show an important aspect of this dilemma. When large amounts of resource are locked up amongst a smaller number of old wily survivors then the system as a whole suffers through having a smaller overall sustainable population and thereby presumably lowered diversity and means of generating innovation and other new traits. Various organisations and societies as a whole show this effect when work-forces or populations experience a steady shift in age demographic towards older and higher paid/richer survivors who inevitably also consume more resource. There is scope to investigate this tradeoff in the context of various game and conflict resolution frameworks [25].

The experiments with a variable camouflage effectiveness parameter also show interesting results and the system as a whole drives the effect of this parameter downwards as it achieves a new level of sustainable population size. We can either regard the camouflage value as a controlling parameter or as an emergent effect or signal that is set by the system itself through evolutionary effects and actions.
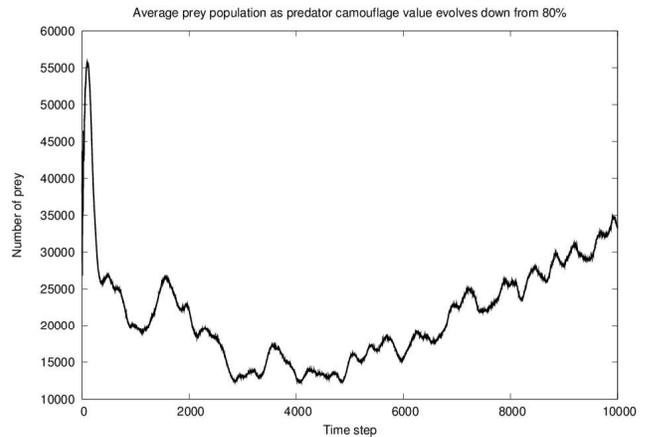

Figure 9: Plot showing the effect on prey population as predator camouflage values are allowed to evolve naturally over time. All predators were initially allocated a camouflage value of 80%. The plot shows the average populations over ten runs with different random number seeds.
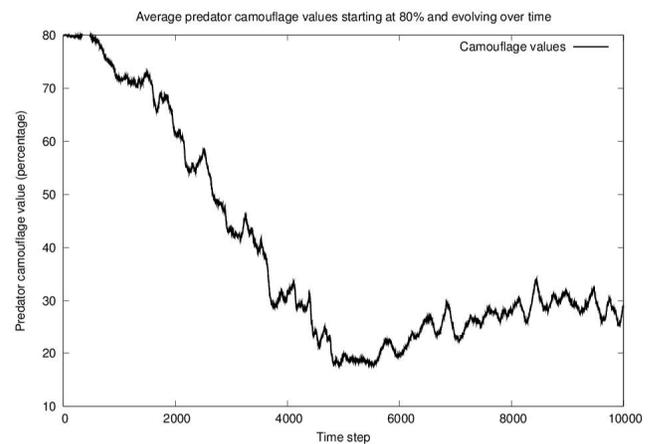

Figure 10: Plot showing how the predator camouflage values evolved over the simulation shown in Figure 8 and Figure 9.

It appears the the camouflage parameter can be quite effectively adjusted by the evolutionary process itself as shown in the experiments in series 3. We might expect that the long-term steady-state average value of the camouflage parameter - about which boom-bust oscillations occur - might itself vary with other long-term parameters like "availability of grass". If other effects have driven the system to high overall sustainable population levels of prey then it might then be viable for a greater number of older, camouflaged hunters to be able to live off such a population without causing it to crash.

We have seen in experiment 3 that the camouflage value tends towards a mean of around 25% around which damped oscillations will continue to occur over time as the system equilibrates itself. It is not clear if this is a universal or special value or if it is in fact related to other parameters and ratios within the model.

The fluctuations in the populations' camouflage value could also be measured over a longer series or differently seeded independent runs. Changes in the variance or a related statistic might give a good indication of whether the system has reached a dynamical equilibrium value for mixed prey and predators with differing camouflage effectiveness ratings.

Work has been reported in the literature on the effect of altruism amongst agents in a population model [26]. It might be feasible to incorporate some deliberate altruism on the part of some or all animats whereby they might give up an individual advantage in times of scarcity to benefit the population as a whole [27]. This is beyond the scope of our present animat agents which at present are only driven by highly localised and selfish goals.

We have implemented camouflage as probabilistic tendency for a predator to evade detection. A single number thus encapsulates any variation or contribution from spatial environment and features. Nevertheless this simple approach does highlight systemic effects and unexpected consequences of over successful hunters with high camouflage ability. This notion of a particular special skill or trait is potentially a useful one and our model framework can quite likely accommodate other traits implemented in this manner.

7   Conclusion

We have shown how a trait like camouflage can be introduced into the microscopic individual behaviour of predators in an animat population of a large scale agent based simulation model. We have see how this leads to greater success (longer lifetime) of individual predators and hence a greater chance for them to pass on this trait to the predator population as a whole. This in turn leads to higher numbers of successful older predators which leads to a crash in the population of prey.

This represents an interesting case of a trait that is good for the success of individuals being in fact bad for the overall system population of combined predators and prey together.

It is also reminiscent of effects of other systems when older individuals develop personal survival traits and live on past the life-cycle that is optimal for the overall population.

There is scope for further work on a floating camouflage parameter allowed to evolve when other system-wide parameters are varied. It would be interesting to test whether highly successful camouflaged hunters are better able to survive - and hence sustain a high camouflage factor - when prey are made plentiful by some other factor, or whether the long term ratio of around 25% is a universal value. Another area for further study would be to introduce a number of different subspecies or "tribes" of predators that have different fixed camouflage ability./traits and which therefore compete with one another. Different such tribes might fare better r or worse in spatial regions depending upon the prevailing average prey abundance.

We believe there is continued scope for microscopic large scale simulation models such as these for investigating trade-offs between individual success and system wide success or sustainability. This approach could be useful for exploring collective behaviours and effects in work-forces as well as societal systems.

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