Using behaviour trees to simulate a forest ecosystem

GROUP 4: 3

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Abstract

The nature on our planet is essential in order for all living creatures to survive. One example of a natural environment is the forest, in which both plants and animals live and interact with each other. How these interactions work, and how these species affect each other is interesting, but due to the risky, potentially dangerous, and time consuming nature of performing experiments on populations in the wild, simulations must often be used to observe how species act. In this report, a simulation of a forest ecosystem has been implemented using behaviour trees, in which complex organisms interact with each other. More specifically, the ecosystem contained grass, earth, water, weather, flowers, bees, rabbits and foxes. The rabbits and foxes had genetic traits that were passed on to offspring. The ecosystem was observed in order to determine its stability, and to see how the genetic factors affected the foxes and rabbits. The results showed that the system had trouble stabilizing, but that some organisms could stabilize with each other. The problems revolved around the organisms dependence on each other, and the system's complex nature making it hard to find good solutions. The genetic factors seemed to evolve in the same direction for both foxes and rabbits, but due to the lack of stability in the system, no real conclusions can be drawn. Further research must be conducted in order to find a stable system in which genetic factors can be more thorougly observed.

1 Introduction

An integral part of the survivability of the planet Earth is its nature. Many different environments exist, such as oceans, jungles and deserts, and these make it possible for organisms to survive.

One example of such an environment is the forest. Forests house many different species of many different types, including both plants and animals. All these species depend on each other in order to survive, since some traits of one type of organism may affect the survivability of another type of organism [1]. Furthermore, these ecosystems help make it possible for all living creatures on Earth to survive through their creation of oxygen.

A simulation is a test of a system in which the original system is not tested on. Instead, an approximation of the system is used to determine the results of the tests. This is useful for several reasons. It allows for risky tests, with potentially dangerous effects, without any real consequences. Furthermore, these types of tests can often be much faster and much cheaper to perform due to the use of efficient computers [2].

Due to the nature of ecosystems, it is hard to perform many tests. For instance, some experiments may affect the populations of species in the system, which can endanger the entire system itself, leading to disastrous consequences that may affect the entire globe. Moreover, ecosystems do not change rapidly. Changes may take several years before they are noticeable, and therefore many tests may not be feasible to perform. Simulations are therefore a perfect tool when performing tests on nature.

In this paper, an ecosystem of a forest is set up and simulated in order to determine how species interact and affect each other over time. Artificial intelligence (AI) for several types of organisms has been implemented with respect to how the organisms behave in reality. These AIs are controlled using behaviour trees and exist in a simulated two dimensional world representing a forest. Furthermore, some organisms contain genetic factors that allow them to mutate over generations.

The simulations were done to see if a stable ecosystem could be produced, and to test how species interact with each other. Moreover, the genetic factors were observed to determine in which way organisms survive the best. The results showcased that species have a definitive impact on each other. Furthermore, they showed that the ecosystem had trouble stabilizing, mainly due to these interactions between species and the large amount of variables that affect the system. More information regarding these results can be found in section 4.

1.1 Contribution

Several papers have been written on the topic of ecosystem simulations. Different variations, such as the use of mathematical models and various environments, have been presented. This paper contributes to this field through the explicit use of behaviour trees to model the organisms in the system. This results in a decentralized system in which agents are not controlled by a general process. This is interesting due to the behaviour trees simplifying the process of creating complex organisms, that act on their own just like in a real ecosystem.

1.2 Outline

In section 2, similar papers are presented. The work in them and how it relates to this report is described. In section 3, the implementation of the ecosystem and the AI of the organisms is described in detail. The reasoning behind the choices made is explained. In section 4, The experiments are presented. How the experiments were performed, what was observed and the results of the experiments are described. The results are also analyzed to determine the reasons for them. Finally, in section 5, the paper is summarized and conclusions are drawn from the results.

2 Related work

In this section, various papers related to this one are presented. Their contents and how they relate to this paper are briefly described.

[3] presents behaviour trees as an alternative way of programming agent logic, compared to finite state machines. The paper also describes how behaviour trees work and provides pseudo-code for their implementation. The paper concludes that robustness and safety are preserved in behaviour trees, compared to finite state machines, while providing a higher level of modularity. This was useful knowledge for this paper's implementation, as switching priorities of organisms and reusing components became really simple. Modularity helps a lot in these cases.

In [4], tests were performed in Australia to determine if foxes affect the population of rabbits. Foxes were reintroduced to areas in which they had previously been removed, in order to see how the rabbit population was affected. The results were inconclusive, with some areas being affected by the foxes and some not. One potential conclusion was that rabbits can recover from and become unaffected by fox introduction once they reach a critical mass. [4] relates to this paper by looking at population amounts for foxes and rabbits. However, these tests were done in the real world, instead of using a simulation.

In [5], neural networks and genetic algorithms were used in order to create organisms that act in an ecosystem. The networks took sensor information (such as eyes) as input, and modified limb movement as output. The genetic algorithms were used in order to find the optimal networks in regards to survival. The results showcased an ecosystem with believable behaviour, with organisms moving reasonably and interacting naturally with each other. [5] can be seen as an extension to the basic genetic tests performed in this paper.

In 2009, Robin Gras at the University of Windsor developed a platform called EcoSim which is an individual-based predator-prey ecosystem simulation in which agents can evolve [6]. Each agent has a behaviour model which is represented with a fuzzy cognitive map. The map represents connections between information from the world like nearby food and predators, internal animal states like fear and hunger, and actions like running or reproducing. EcoSim has been used for several scientific studies. [7] used EcoSim to see how small randomly generated obstacles can influence gene flow. The results showed that introducing more obstacles lead to a direct increase in the speed of evolution.

In [8], EcoSim was used to research species abundance patterns. To analyze patterns, the Fisher logseries was used and the distribution generated by this logseries was compared to observed simulations. The results showed that the species distribution in EcoSim for small samples follows the distribution observed in nature, but it fails to do so for larger samples. However, the authors state that these results are sufficient enough to use EcoSim for analyzing and predicting abundance patterns in real worlds. This relates to the work done in this paper in that it looks at the populations of species. However, [8] focuses on the actual population amounts, whereas this paper focuses on what these amounts mean for the ecosystem.

3 Method

In this section, the implementation of this paper's ecosystem and the AI for its organisms is presented and described.

The forest ecosystem implemented in this paper is represented by a two dimensional grid world in which each cell can contain different components. There are four layers for each cell: a water layer, a ground layer, a flower layer and an animal layer. The water layer determines the amount of water in a cell, and if this amount is high enough, it results in a water pool being formed. The ground layer determines if there is grass or earth in a cell, or if an immovable object is positioned there. The flower layer determines if there are flowers in a cell, and how many there are. The animal layer determines if there are animals in a cell. It also makes sure that there are not more animals than is possible in a cell. Each cell has a capacity of animals it can contain. This is affected by immovable objects from the ground layer.

The ecosystem and its components change over time steps. Each organism performs an action each time step by going through its behaviour tree. In the following subsections, these organisms' implementations will be described. Since there are too many variables to describe everything in detail, only the high level features of each organism are described. For the full details and the code controlling the organisms, see `https://github.com/Xaril/forest-eco-system`.

3.1 Earth

Earth is one of the possible components in the ground layer. It has a water capacity and a water amount. If the water amount exceeds the water capacity, the earth becomes water and all vegetation on it dies. Water in the earth cell slowly spreads to nearby cells to level out.

3.2 Water pools

Water pools are randomly initialized around the map at the beginning of the simulation, and are used mainly as a water source for animals. Water pools have a capacity and an amount of water. If the amount of water exceeds the capacity, the water floods to nearby cells. If the water pool runs out of water it dries out and becomes earth. Adjacent earth and grass cells slowly drain the water from the pool as well.

3.3 Grass

Grass is another possible component in the ground layer. It grows from seeds that are spread by wind from nearby grid cells. It is dependent on the cell's water amount, with too much or too little water killing the grass. When the amount of grass reaches a certain threshold, it starts to create seeds.

3.4 Flowers

The flowers implemented in this paper have a behaviour based on the information in [9].

The flowers grow from seeds. These seeds are dependent on water in order to grow. Too little water or too much water will kill the seeds. If the amount of water is correct, a flower will be created. This flower depends on the water levels in the cell in the same way.

Flowers generate nectar. This nectar generates a smell that is spread by the wind and that attracts bees. Flowers also generate pollen. The amount of pollen is dependent on the size of the flower. This pollen is attached to bees who gather nectar. If pollen from one flower reaches another flower, the flower gets pollinated and seeds are produced. Rabbits eat flowers, and if the flowers contain seeds, these seeds are eventually excreted by the rabbits such that new flowers can grow.

3.5 Bees

The bees implemented in this paper have a behaviour based on the information in [10] and [11].

Bees are flying insects, known for their role in pollination. They live in hives and collect nectar from flowers. Nectar is then taken back to the hive and stored there. In addition to nectar storage, the beehive is used as a resting place and for creating new bees. The reproduction of bees is omitted since their main role in this simulation is to pollinate flowers.

In this paper, two types of worker bees are implemented: scouts and recruits. The scout's main role is to search for flowers with nectar. Scout bees' behaviour follows the following priority: If the bee is tired, it flies back to the hive. Otherwise, if no nectar location is known, the bee searches for nectar. Otherwise, if a nectar location is known, the bee flies to the hive to communicate this to recruits.

Scouts search for food by going to the direction where the nectar smell is largest. If a scout bee does not sense any nectar smell it will try to move away from the hive in a random direction.

The recruit's main role is to collect nectar and take it back to the hive. Recruit bees perform actions according to the following priority: If the current hive does not have any living scout, the bee becomes a scout. Otherwise, if a location of nectar has been communicated by a scout, the bee goes and collects the nectar. Otherwise, if no nectar location is known, the bee waits in the hive for the scout.

Each hive has to have at least one scout at all times. If the scout bee dies, one of the recruits will take its place. No matter the target location a bee is flying to, it always has a probability to fly one step in a random direction. This is done in order to simulate bee flying patterns.

3.6 Rabbits

The rabbits implemented in this paper have a behaviour based on the information in [12].

Rabbits are monogamous herbivores that feed on grass and flowers. They drink water from the water pools in the system, and sleep in high grass or burrows. The burrows are also used for giving birth to and nursing children.

The rabbits in this paper have a behaviour that follows the following priority: If the rabbit is newly born, it stays in the burrow. Otherwise, if the rabbit is asleep, it continues sleeping until it should wake up. Otherwise, if a fox is in the rabbit's vision range, it avoids it. If the rabbit's burrow is nearby, it runs towards it, otherwise it runs away from the fox. Otherwise, depending on the level of hunger, thirst and tiredness, the rabbit eats, drinks or sleeps. If the rabbit is hungry, it prioritizes eating flowers. If no flowers are nearby, it prioritizes high grass over low grass. If the rabbit is really hungry, it prioritizes the closest food source instead. If the rabbit is thirsty, it moves towards the closest water source. If the rabbit is tired, it moves towards the burrow if it is nearby. If not, it moves towards high grass. If no high grass is nearby either, it creates a new burrow. Otherwise, if the rabbit has to defecate, it defecates. Otherwise if the rabbit has children who require nursing, it moves towards these children and nurses them. Otherwise, if the rabbit is pregnant and about to give birth, it creates a new birth burrow. Then it gives birth to the children. Otherwise, if the rabbit can reproduce and has a partner which is nearby, it moves towards the partner and reproduces. If the rabbit does not have a partner but a suitable rabbit is nearby, it moves towards the rabbit and makes the rabbit its partner. It then reproduces with it.

Rabbits have a genetic factor that affects their actions. This genetic factor increases movement speed and reduces tiredness at the cost of increasing hunger and thirst. The genetic factor is inherited from parents, with small mutations occurring.

The rabbit burrows increases the capacity of the animal layer in a cell. If a rabbit is in a cell with a burrow, it is assumed to be inside the burrow. If a burrow has not been used for a certain amount of time steps, it is destroyed.

When specifically moving towards targets, the rabbits use the A* algorithm [13].

3.7 Foxes

The foxes implemented in this paper have a behaviour based on the information in [14].

Foxes are monogamous carnivores that feed on rabbits. They drink water from the water pools in the system, and can sleep anywhere. They use dens for giving birth and nursing newly born children.

The foxes in this paper have a behaviour priority similar to the rabbits. There are a few differences, however. First of all, the foxes have no enemies and can therefore sleep anywhere. Thus, they do not look for places to sleep when tired, but just fall asleep on the spot. Secondly, the act of defecating does not affect the system (since foxes do not digest seeds), and as such, this action has been omitted. Thirdly, the foxes do not eat grass or flowers, but must instead hunt rabbits. Rabbits leave their scent in a grid cell for a certain number of time steps, and foxes can utilize this to head in the direction of rabbits, if none are nearby. Finally, after fox cubs are old enough to leave the den, they do not act independently. For a certain number of time steps, they follow their mother around, drinking when she drinks and sleeping when she sleeps. The mother hunts for her cubs, and makes sure they are given food as well.

Aside from the above mentioned differences, the foxes prioritize their actions in a similar fashion to rabbits. They have the same genetic factor as rabbits.

3.8 Weather

Aside from the organisms inhabiting the ecosystem, the ecosystem is also affected by weather. The weather consists of rain and wind and is simulated in each simulation step. Every so often, there is certain probability that it will rain. In this simulation there are three types of rain: light rain, medium rain and heavy rain. Each type has its own probability of occurring, and they differ in the amount of water they produce.

Wind direction changes over time. Four different types of wind are implemented: calm wind, breeze, gale and storm. Each type has its own probability of occurring, and they differ in the range things affected by wind moves.

Wind direction and speed affect how grass seeds and nectar smell is spread in the system. The higher the speed, the farther it spreads.

4 Experimental results

In this section, the setup of the experiments conducted is described. Moreover, the results from the experiments are presented and analyzed.

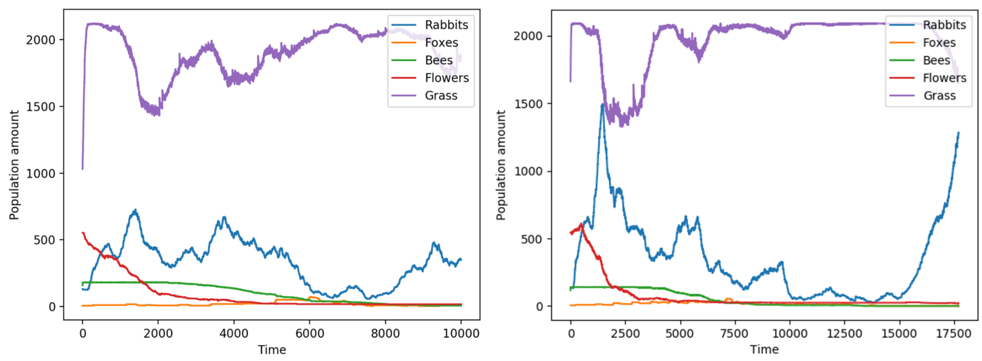

Figure 1: Plots showing the number of animals per species and the amount of grass in each timestep for 10000 iterations (left) and 20000 iterations (right)

4.1 Experimental setup

During the implementation of the ecosystem, a visualization tool was implemented in order to see how the organisms acted over time. This was useful in order to determine if the AI was working or not, and to get an overview of the ecosystem. For the experiments, however, these visualizations could not really say much about the stability. Instead, a plot tool was implemented which ran the ecosystem simulation for a fixed amount of time steps, collecting information about the organisms and then plotting the results. In the following subsection, these plots will be presented and analyzed.

4.2 Experiments

Figure 1 shows the number of animals for each species during different time steps for two different simulations. The plots show that the main species that were stable during the simulation were rabbits and grass. However, foxes were also able to survive for these two simulations, albeit with a much lower population amount compared to rabbits. This was not the case for all simulations, and foxes often went extinct. This, and the reason for bees' and flowers' extinction, is attributed to the high dependency between species, and the number of variables controlling the organisms.

Bees are highly dependent on flowers, which are their only source of food. Both plots in Figure 1 show that the bee level is stable until the number of flowers starts to decrease rapidly. All flowers die before the 4000th time step in both plots. The flowers were not able to survive for longer than that because of the very high complexity of their reproduction process. First of all, the flowers have to be big enough to produce pollen. They then have to be pollinated in order to produce seeds, and then have to be eaten by rabbits. The rabbits have to survive long enough to defecate the seeds, and the earth has to have the right amount of water for the seed to grow. This process is quite long and can easily be interrupted by some external factor. One of the most common factors that interrupted this process were rabbits which tend to live in large herds. After a rabbit defecates flower seeds there is a high probability that a lot of other rabbits are nearby and that they will eat the flowers before they grow and get pollinated. This could potentially be fixed by modifying the parameters regarding the number of bees, the number of flowers, the reproduction rate, and so on, but this search is very complex due to the many variables, and no good solution was found during the course of this project.

The plots also showcase a strong correlation between rabbits and grass. An increase in the number of rabbits will, with a short delay, result in a decrease in the amount of grass. This is confirmed when looking at Figure 2, which simulates the environment for 100 000 time steps. This plot both showcases the stability of grass and rabbits when no other species are involved (as they, as can be seen, go extinct after around 10 000 time steps), and that the negative correlation between the two species is maintained over time.

The foxes' only source of food are rabbits. It may be hard to see but Figure 1 shows that the number of foxes and the number of rabbits are correlated. An increase in the number of rabbits will lead to an increase in the number of foxes, since more food increases survivability. This is not always good for the foxes, however. As was mentioned above, rabbits are highly correlated with grass; with lots of rabbits, the grass amount becomes low. This means that when lots of rabbits exist, there is almost no grass but also a lot of foxes. Thus, the number of rabbits can decline suddenly and quickly as is shown in Figure 2, where the population curves are very steep, and occur very often. This decline affects the foxes the most. They are not as resilient to the changes in rabbits as needed. This often results in the rabbit population amount becoming too low, and foxes going extinct due to the lack of food. In the best simulation, foxes managed to survive these steep declines for about 20 000 time steps, which corresponded to about 20 fox generations. This interplay between animals could potentially be fixed by tuning parameters such that the number of rabbits does not change so rapidly. However, as mentioned before, the number of variables to tinker with resulted in no solution being found.

Figure 3 shows the plots of the genetic factor for rabbits and foxes in two different simulations. It can be seen that the genetic factor changes quite

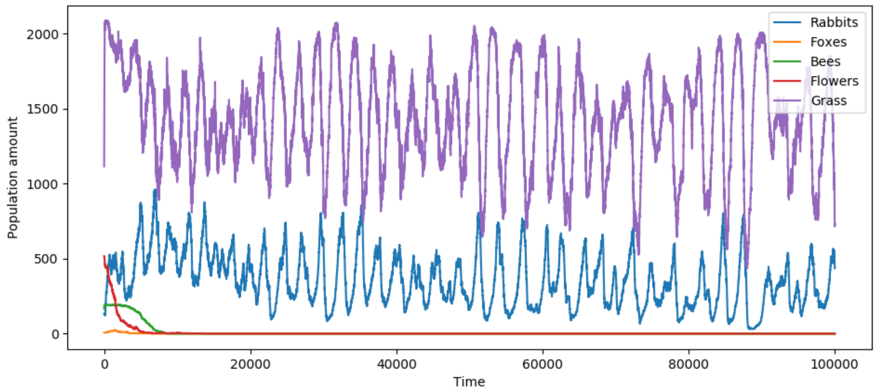

Figure 2: A plot showcasing the population amount for different organisms during a simulation of 100 000 time steps. As can be seen, all organisms except grass and rabbits die fairly quickly.

similarly for both species. This means that if for instance rabbits get faster, then only fast foxes can survive, or vice versa. However, it is hard to draw any general conclusions since the ecosystem could not stay stable for a very long time.

5 Summary and Conclusions

In this paper, a forest ecosystem simulation has been implemented, in which species such as bees, flowers, rabbits and foxes interact with each other. The organisms were implemented using behaviour trees, as this simplifies the process of creating complex behaviour, and foxes and rabbits evolved over generations using a genetic factor. Tests were then conducted in order to find out if the ecosystem could become stable, and to observe how the genetic factor changed.

The results showed that the organisms were dependent on each other and that this dependence, combined with the complexity of the organisms due to their many variables, made it hard to stabilize the system. More specifically, the following results were found. Bees were fully dependent on flowers, but flowers used a slow and complex reproduction process that made it impossible for them to survive in an environment where rabbits are abundant. Rabbit and grass amount were highly negatively correlated, with an increase in rabbits resulting in a decrease in grass. This relationship, although volatile, was stable and could be maintained for a long time. It did however take its

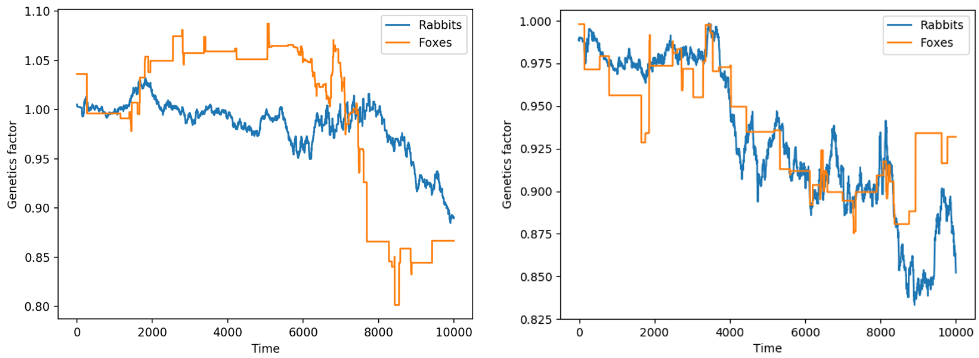

Figure 3: Plots showcasing how the genetic factor changed over time during simulations.

toll on the fox population, which was heavily dependent on rabbits, but not resilient to sudden declines in the rabbit population.

To be able to stabilize the system, the number of rabbits would most likely have to change less drastically. How this can be done without compromising the nature of organisms remains to be seen, and is taken as future research.

The genetic factors implemented in the foxes and rabbits showed that the animals evolve in a similar fashion. It seems that one animal's changes requires the other animal to change in the same way in order to survive. To make sure that this is the case, a more stable system would be required, and this could therefore also be researched further in a future paper.

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