



Open-ended Evolution in Flocking Behaviour Simulation

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Abstract. In this research we tried to apply open-ended evolution to breed controllers for artificial organism which would be able to manifest flocking behaviours. In comparison to the previous work in this area the artificial world created in our system is characterized by significant diversity of organisms. Animals were equipped with double and dynamic sight, which were suggested by other authors in their works. In experiments, many different behaviours were observed, which were very similar to those in nature, for instance: the escape of herbivore from predators, making herbivores route towards plants or a pursuit of predators after herbivores. Another interesting behaviour was grouping of predators around plants, where the probability of meeting herbivore is greater than in other places. The most advanced behaviour was creation of flocks, which was the goal of experiments. The observed motion of animals looked natural. However, to the full success it was necessary to apply steered evolution.

1 Introduction

It has been ages since people have been admired flocking behaviour of animals. They have been fascinated by a veering formation of birds or a shoal motion. With the development of computer techniques they try to simulate them in computer animations but it is not an easy task for graphic artists. A smooth motion needs many subsequent frames, drawing of which is very arduous and laborious work. Additionally, each correction of route of an individual needs to take into consideration many other individuals which makes the problem more difficult. That is why this problem has been studied by many researchers. Traditional approaches are based on simulations of mathematical equations of motion ([5, 2, 9, 14]). Their construction usually requires advanced mathematical skills and exact knowledge about the studied animal's behaviour.

One of the first advanced other solution in this area was proposed by [10]. It is the main way of solving a simple flock (as well as herds and schools) simulation so far. In this approach each individual is implemented as independent element called boid. Its behaviour is controlled by rules. They determine the behaviour of a given individual on the basis of its environment (position, direction of motion of other member of flock and information about obstacles). Local interactions cause the flocking behaviour on the global level (of a whole group). In order

to create virtual model of moving flock with using cited above method it is necessary to formulate and implement the set of rules defining single individual behaviour. The approach described by Reynolds in his works ([10] and [12]) was inspiration for many other researchers. For instance, [1] present rules based on fuzzy logic. Another example based on crisp rules is given by [13]. This work enhances the basic Reynolds' system in several ways. First of all it uses three distinct species of agents. Rules are also the basis of the system described by [8]. In this system at each time step, the positions and directions of individuals are updated by a set of simple rules. Individuals perceive the environment around them and can sense the distance between them and other individuals.

Often tuning of these rules is very time consuming. The solution for this problem carries out an application of evolutionary algorithms. As an example of such approach the paper of [16] may be cited here. In this work the authors try to breed population of individuals manifesting flocking behaviour. Artificial fishes move in three-dimensional world. This motion is controlled by a neural network, which is evolved during evolution. Evaluation of a single individual is consisted in creation of clones of this individual (having the same genotype). Then, this group is placed in the environment, its behaviour is monitored and evaluated with a fitness function. In the experiments some elements of flocking behaviour have been noticed, which confirmed that it is the proper direction of studies, but in general, the authors evaluated that the results were little realistic and behaviour of artificial animals does not remind of the one, which exists in reality. The reason that design failed, besides the problem with a proper design of fitness function, the authors have pointed to poor environment in created artificial world. Flocking behaviours in nature are the result of a diversity of external factors as, for instance, a temperature gradient, a light gradient or arrival of other species. Authors – [3] applied genetic programming to breed flocking behaviors. The fitness function is given by the user in an interactive way.

The achievements described in the paper of [15] can be perceived as one step ahead in comparison with the results presented in the work of [16]. These authors also applied evolutionary approach but instead of explicitly defined fitness function they decided to use open-ended evolution, giving the organisms more freedom in their development. Additionally, the environment has been enriched in other species. There were plants, which were food for the first species – herbivores that are the food for predators. The assumption of this system was that flocking behaviours should arrive as a result of conditions existing in artificial world. However in this project the problem with definition of flocking behaviour concept has arrived. It was not necessary to define fitness function because in open-ended evolution the aim of each organism is surviving, that is expressed as possessing of a sufficient level of energy. Here the statistical approach was applied. The common feature of both papers ([16] and [15]) is the way of perceiving surrounding world by individuals. This resulted in the type of information, which was provided as inputs for controllers of individuals. In both cases this information is static. Such organism is informed about location of other objects, but it is not conscious of objects motion.

In the paper of [4], each individual establishes its own neural network, as well. But additionally, reinforcement learning method in a complex and dynamical environment is proposed during evolution.

Flocking behaviour is dynamical phenomenon. It seems to be reasonable to equip the animals in artificial world with the ability to register the objects movement. This suggestion was also the conclusion of [11] but was not implemented nor tested. With this in mind the aim of our research was to built an artificial world in which various flocking behaviour can be observed. As it has been suggested in the previous works of [11] and [16] this ability of artificial animals should be achieved with using open-ended evolution and should be caused by diversity of organisms living in the artificial world.

The paper is organised as follows. The next section presents the assumptions and details of the system *Flock*, where the artificial world is implemented. It enables investigation of behaviour of animals and easy settings of parameters for experiments. Next, the course of experiments and obtained results are described. The paper ends with conclusions and a suggestion of a future enhancement of the system.

2 The system *Flock*

As opposed to the system proposed by [15], in our system the artificial world is two dimensional. This assumption results from a greater ability of an animal behaviour observation on a computer monitor. The second reason is efficiency problem (two dimensional world is less computationally expensive). Although it is difficult to generalize the obtained results into three dimensional world, it is worth to notice that many flocking behaviour may be observed in two dimensional world, for instance, animals living in the flocks (packs) on a land.

The world in our system is settled by plants and two kinds of animals: herbivores and predators. All animals have ability to move. The plants are motionless, of course. In order to limit the speed of animals its maximal value is defined for each species: i.e. *maximal speed of herbivore* and *maximal speed of predator*, respectively, which are the parameters set by the user.

2.1 Neural controller of an individual

A behaviour of each organism, more exactly its actual value of a speed vector, is determined by a neural network (NN). Information about nearest surroundings is given on inputs of NN. Its outputs determine a change of the speed vector for a given individual. In other words, the neural network influences the motion direction and the speed of the individual. Interactions between organisms are the results of mutual location. The applied controller is three-layered feedforward neural network presented in Fig. 1. The hyperbolic tangent is applied as an activation function. In the output layer there are four neurons. The outputs of first two neurons determine motion direction change. The first one refers to the turn to the right, the second one to the left. The difference between them

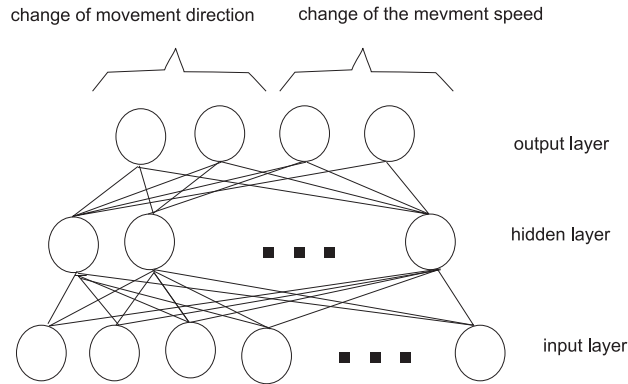


Fig. 1. The architecture of the neural controller

multiplied by the parameter *maximal angle of turn* gives the actual direction of the speed vector. The outputs of two remaining output neurons define a change of an animal speed. Similarly as in the previous case, the difference between two outputs is calculated. This value determines the change of the speed vector length of an individual. The change is limited to the values from an allowed range defined by the user.

The number of neurons in the hidden layer is set by the user, as well.

The number of neurons in the input layer depends on the way of perception of the external world by an animal. The animal is able to observe only those objects (animals or plants), which are within its reach. This means that its distance to the object is less than minimal allowed value, which is set by the user. This parameter is called *sight radius* (Fig 2). In order to give an animal information

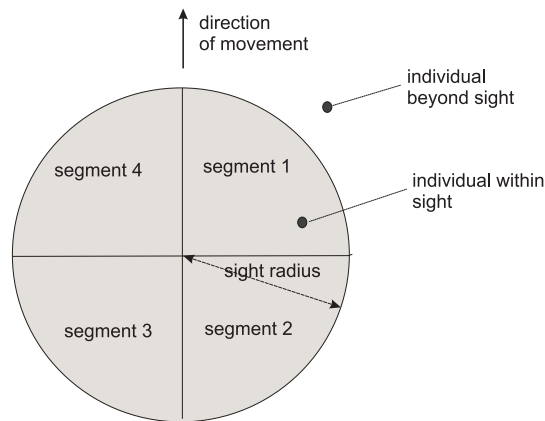


Fig. 2. The principle of vision system of animal

about surrounding objects placement the circle representing the area being in its reach is divided on a number of segments. A boundary between the first and the last segments agrees with the direction of the animal motion. In each segment the following information is essential:

- the number of plants,
- the number of herbivores,
- the number of predators.

More precisely, the location of each object is also essential. That is why information about existence of a given object in the segment is scaled depending on its distance from an animal and all these values are summed. This result is given for one neural network input. Because three different objects types are identified in the system there are three neural network inputs assigned to each segment.

Similarly as in the previous works referring to evolutionary development of collective behaviour (for instance: [16], [15]), animals are equipped with double sensorial system, but with various radiuses. The additional system has radius equal to a half of *sight radius* of the basic vision system. This approach enables delivering information about objects existing in nearest, as well as further, surroundings. In this way an animal has information, which objects that it sees are closer to it. It is expected that such double sight allows to evolve a sophisticated behaviour of animal that depends on an angle in which objects are visible for an animal but also depends on the distance of the objects from an animal.

For experimental study, the additional vision system may be switched off. According to the suggestions of [16] and [15], the system `Flock` has been enriched by a dynamical vision effect. It is realized by introducing to the controller information from sensor about situation in an animal neighbourhood in two consecutive time steps (from the actual time t but also from the previous time step $(t - 1)$). It makes double the number of neural network inputs but enables to register dynamics of changes. In this way the animal will be able to react on the position of the surrounding it objects but also on the velocity and the direction of their motion.

2.2 Energy flow

Each animal has a given level of energy, which is decreased with every time step by the value defined by *cost of motion* parameter. New animal has a value of energy equal to 0,75 of *max energy*. This setting prevents a favouring of an individual that arrives at the end of evolution and does not represent a well adapted individual. An individual with energy equal to 0 dies and it is removed from the artificial world.

An individual loses its energy in various ways. As we mentioned above, every time step energy decreases by the value *cost of motion*. Optionally, cost of motion can be dependent on the value of an animal speed. In this case the lost of energy is directly proportional to its speed. The second possibility of energy loss is a penalty for collisions. In the case two animals from the same species will

be located in the distance less than assumed value defined by parameter *collision distance* then both of them lose energy. In this situation, the movement of both animals is not disrupted nor the speed vector is changed.

In order to increase the level of energy, the animals have to eat organism located directly under them in the food pyramid. This means that herbivores eat plants and predators eat herbivores. If a distance of an animal from its food is less than defined by a parameter *distance to food* the plant or respectively a herbivore is being eaten.

2.3 Evolution

Neural networks, which control a behaviour of animals are evolved by evolutionary algorithm. The chromosome represents weights of this neural network (Fig. 3). Its architecture during one simulation is fixed. One gene refers to a

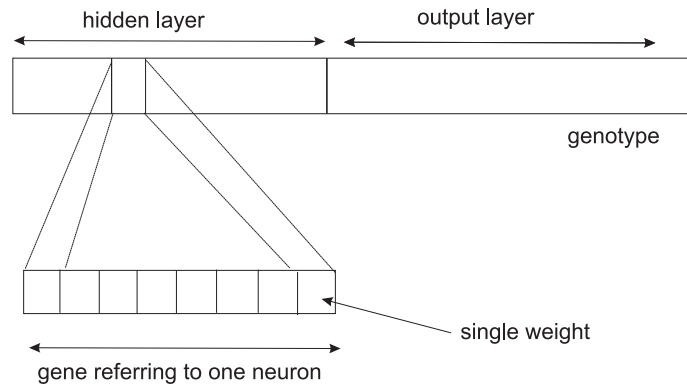


Fig. 3. The chromosome structure

given neuron. It contains weights on outgoing connections. Single weight is encoded as a real number. The number of individuals in each generation is defined by the parameter *population size*. A typical evolutionary algorithm scheme is applied. It means that in each generation, some of individuals are selected for reproduction. Then, they are exposed to genetic operations: crossover and mutation. One point crossover is implemented in the system. Mutation occurs with an assumed probability. It relies on addition or subtraction a small value to a mutated gene. Evolution in *Flock* system is open-ended. This requires that the only mechanism of evolution is natural selection, which consists in elimination of individuals that are not able to capture or to kill a sufficient amount of food to survive. During the first experiments with the systems it turned out that animals rewarded for staying with individuals from the same species perform better taking into account their flocking behaviour. That is why optionally the animals can be rewarded by increasing its energy proportionally to the number of animals from the own species existing within the sight of a given animal.

The animals live an assumed number of time steps. Next, they are evaluated and reproduced – a new generation is created. Organisms from the previous generation are removed from the artificial world. The measure of their fitness is the value of energy. Roulette wheel is used as a selection method ([6], [7]).

3 The course of simulation

The simulations can be proceed into three mode: real, accelerated and step by step. In the first one, the subsequent steps of simulation proceed with simultaneous visualization until the evolution is stopped on demand of the user. The accelerated mode proceed in the same way but without visualization. In the last mode one step of simulation is performed, which is shown in Fig.4.

```

Create a new population of individuals
While an actual number of steps in actual generation is less or equal to the maximal
number of steps in generation do
  For each individual
    Give information about surrounding it objects on the inputs of its NN
    Modify its speed vector according to the values of NN output
  end{For}
  For each individual
    Change a position of individual by a value defined by its speed vector
  end{For}
  For each individual
    If the collision with other object exists then modify its energy
  end{For}
  For each individual
    If the value of energy is less than 0,
      then
        Remove this individual
      Create new organism with the use of the previous generation and
      roulette wheel mechanism
      Locate new organism randomly in artificial world
    end{then}
  end{For}
end{While}

```

Fig. 4. The algorithm in pseudocode of simulation a single step in artificial world

4 Experiments

The main criteria to evaluate our artificial world is a satisfaction of herbivores. The aim of the experiments was to test whether in this world arrive flocking behaviours of animals. Because of the large number of parameters in the system, a series of preliminary experiments was performed, the aim of which was to

determine suitable values of parameters that are invariable in the next experiments. The smallest number of simulation steps, needed to appear the evidences of animals adaptation to the artificial world, was the criterion of the choice of parameters values.

4.1 Tuning the parameters

Because the double and dynamic sight are very time consuming in this experiment they were not used. The conclusion from observation of animals behavior in the performed experiments allowed to tune the values of parameters.

The values defined after experiments performed in this series are shown below. They are constant in the next experiments.

- *The number of objects of particular species* – because of the speed of the hardware available to simulation, the number of predators was set to 20. Small population has a negative influence on efficiency of evolutionary algorithm. That is why the number of herbivores was set to 40, because it was the main species, behaviour of which was observed in the experiments. The number of plants is equal to 50. This value is enough to find them by herbivores but as much to make the task nontrivial.
- *The size of the world* – this parameter in connection with the previous ones determines population density, which has significant influence on the development of organisms in the artificial world. In the preliminary experiments a high population density caused unnatural behaviour facilitating survivals of predators. They only gathered near plants and waited for the herbivores.
- *Parameters of evolutionary algorithm* – suitable tuning of evolutionary algorithm is an essential element of success. After preliminary experiments the value of crossover probability was set to 0.8 and probability of mutation 0.001.
- *The number of steps in one generation* – evolution should be long enough in order to eliminate organisms by natural selection which are not adapted to the life in artificial world and to breed flocking behaviour of animals. Too high value of this parameter may cause quick domination of population by individuals that represent local optimum. After some preliminary experiments this value is set to 1000.
- *The number of sight segments* – with the growth of this parameter value the motion of animals becomes stable and smooth, but more complex behaviour has been not observed. That is why this value is set to 4.
- *Maximal turn angle* – modification of this parameter generated many interesting effects. Animals were too sensitive for high value of this parameter, for instance herbivores were able to turn about-face. In the experiments this parameter is set to 0,5 Π rad
- *Energy parameters* – on the basis of preliminary experiments values of these parameters have been set as follows: *plant energy* = 50, *maximal energy of herbivore* = 500, *maximal energy of predator* = 500, *cost of motion* = 1.

These values were chosen in this way that the life length of individual which is not capable of getting of energy is less than a duration of one generation and so as a herbivore energy was sufficient to reach the next plant (an average distance). The energy of herbivore should be sufficient to reach the plant being in its neighbourhood.

- *Perception of world* – in this group there are three parameters: *maximal speed of herbivores*, *maximal speed of predators* and *sight of animals*. After preliminary experiments these values are set respectively: 5, 5, 50. These values allow an animal moving with maximal speed to have in its sight an area, which the animals are able to reach in 10 time units. A bigger size causes a lack of determination in animal motion. Too many stimuli goes to the animal and it reacts simultaneously with all of them, what gives bad results.
- *Reinforcement value* It is set to 0.1. Too high value of this parameter causes an incorrect performance of a neural network. Because of applied activation function, for values where hyperbolic tangent function is flat it is difficult to train the network.

The values of remaining parameters are set differently in each experiment. In all experiments performed in this series arose behaviour that allowed to survive animals in the artificial world. Typically, herbivores made their way towards plants in order to consume them as it is shown in Fig. 5. In all figures in this paper plant is represented as a small square. A herbivore is shown as an empty triangle while predator as a black triangle. The animals had no serious problems with finding plants and moving towards them. However, in some situations the

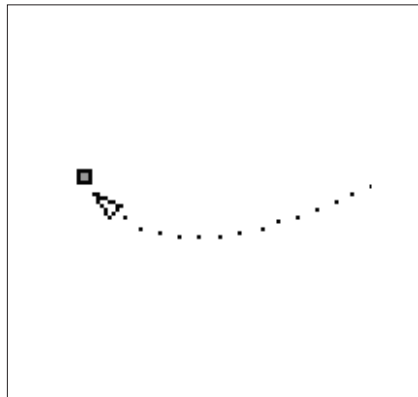


Fig. 5. The herbivore is moving towards a plant (represented as a small square). A herbivore is shown as an empty triangle

simple sight was not sufficient. The animal was not capable to manage situations where a few plants was in its neighbourhood. Sometimes it happened that animal

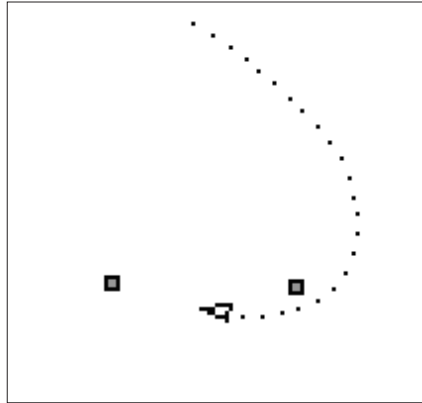


Fig. 6. The problem of herbivore (the empty triangle) with hitting a plant (a small square)

went around a subsequent plants without eating them (Fig. 6). In the result the animal cannot increase its energy.

Additionally, herbivores had a gift to avoid predator attacks. It is worth to notice that they did not apply simple dodges. The herbivore seeing close predator tried to make its way towards him in order to pass it (Fig.7). After this manoeuvre a predator was not able to turn round because of a limited turn angle and in consequence it was not able to catch a herbivore. The herbivore was rescued.

The predators have developed basic mechanisms allowing them to survive in

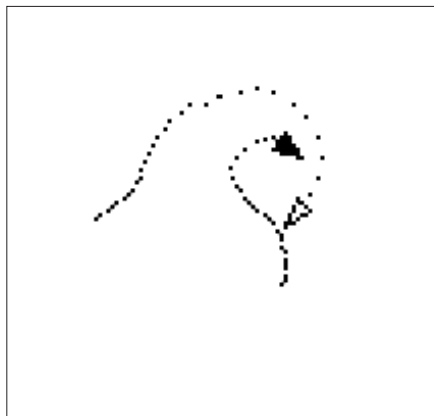


Fig. 7. A herbivore (represented as the empty triangle) tries to escape from a predator (represented by the black triangle)

artificial world, as well. Animals had ability to pursuit of herbivores until to catch them (Fig.8). Because the maximal speed of predators was equal to the maximal

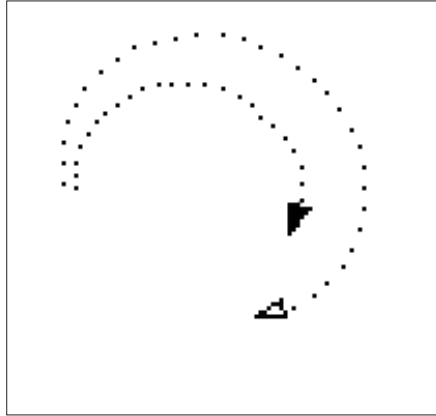


Fig. 8. A predator (the black triangle) in pursuit of a herbivore (the empty triangle)

speed of herbivores the last ones in order to catch their victim applied the method of cutting a corner, which slowly brought them to their goal. Moreover, predators apart from going after herbivores showed the tendency to move to plants (Fig.9). This phenomenon can be easily explained by higher probability to find there herbivores searching for food in this region.

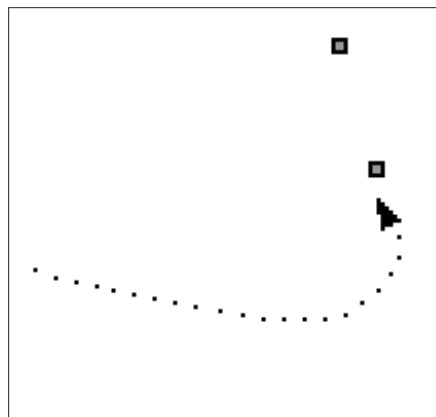


Fig. 9. A predator (the black triangle) moving towards a plant (a small square)

4.2 Dependency of cost of motion in relation of speed

The aim of this experiment was to investigate what is an influence of changes of animals energy depending on their speed on appearance of complex behaviours in our artificial world. In each time step the energy of an animal was decreased in proportion to its speed. The values of parameters that were not set in the initial experiment were amounted respectively to:

- Cost of motion depending on speed – TRUE;
- Dynamic sight – FALSE;
- Double sight – FALSE;
- Punishment for collision – 10;
- Distance to attack – 5;
- Distance to eat plant – 5;
- Distance of collision – 5.

The last three parameters define how close has to be an animal to other object in order to eat it or to run into this object. Unfortunately, the results of this experiment were not satisfying. A higher cost for moving with a higher speed has a negative influence on predators behaviour. They have small willingness

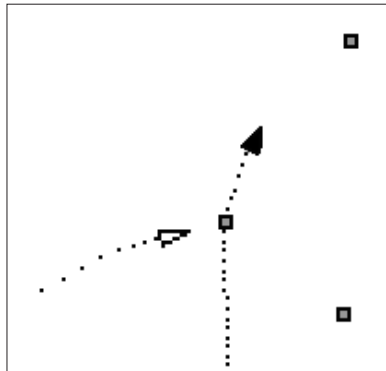


Fig. 10. The predator (the black triangle) ignores the herbivore (the empty triangle) and is moving towards a plant (a small square)

to chase of herbivores. In most cases the predators almost ignored the presence of herbivores. The plants located in their sight radius had much more influence on their motion direction. The predators most frequently followed them. It is showed in Fig.10. That is why a herbivore was eaten only by chance in the neighbourhood of plant, which both species made their way towards (Fig.11). It has been followed that a decreasing of animals energy depending on their actual speed caused the predators were tired after chasing. Because it took place with a high speed, energy resources of hunter were violated. Even the hunt has been

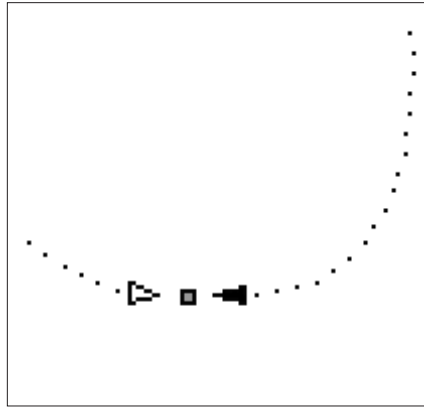


Fig. 11. The accidental collision between a herbivore and a predator nearby a plant

finished with success the victim was exhausted and its level of energy was small. For this reason it presented too small reward for the used energy. That is why in further experiments the parameter *cost of motion dependent on speed* is set to FALSE.

4.3 Elimination of collision between individuals from the same species

Preliminary experiments have shown that animals have no capability to correct a path of their motion, which resulted in collision of individuals from the same species. Often a collision of herbivores happened during a time when they brought closer to the same plant (Fig.12). Because each of them tried to be the first one nearby a plant they run across each other. Similar situations were noticed between predators during their hunting the same victim (Fig.13). Such phenomenon contradicts flocking behaviour therefore next experiments were performed in order to eliminate this undesired behaviour. They focused on balancing of profits and losses. To solve this problem the parameters referring to a collision were changed. The following parameters were tested: *punishment for collision*, *the distance to attack*, *the distance to eat a plant*, *the distance to a collision*. Each parameter was tested with values from a wide range in order to establish optimal values, which are set as follows:

- Cost of motion dependent on speed - FALSE;
- Dynamic sight – FALSE;
- Double sight – FALSE;
- Punishment for collision – $\langle 5; 100 \rangle$;
- Distance to attack – $\langle 5; 100 \rangle$;
- Distance to eat plant – $\langle 5; 100 \rangle$;
- Distance to collision – $\langle 5; 100 \rangle$.

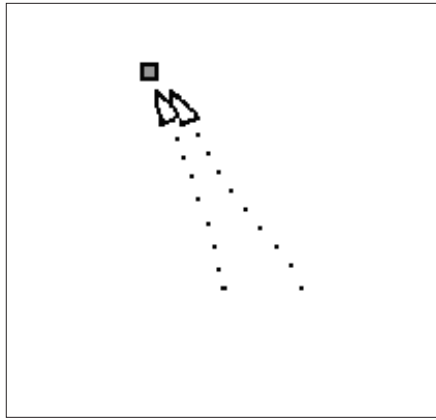


Fig. 12. A collision of herbivores nearby a plant

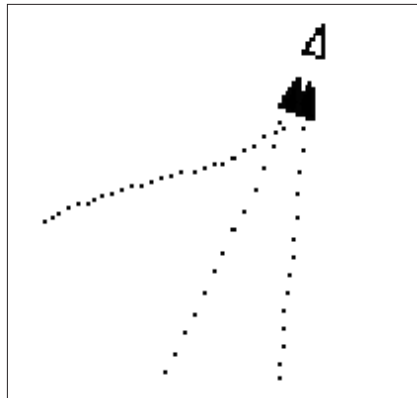


Fig. 13. A collision of predators during a pursuit of herbivore

It is worth to mention that the parameters referring to a collision were selected to ensure that the distance between animals of the same species was much larger than this one needed to catch a food (a plant for herbivores and herbivores for predators).

The best results were obtained for *punishment for collision* = 50, *the distance to attack* = 5; *the distance to eat plant* = 5; *the distance to collision* = 5. Decreasing the value of the last parameter has brought expected effects. Its values less than 5 caused that the principles managing our artificial world have become unrealistic. For instance, a predator that gained momentum moved close to a slowly moving herbivore without any harm made to it. It is because the last step before a catching of victim was too far from herbivore, the next step after overtaking a victim was also in the safe distance from a chased animal.

Unfortunately, none of flocking behaviour was observed in this series of experiments. Both, herbivores and predators have found the way to cope with problems in artificial life without any collective working. The barrier in the flocking behaviour emergence may be caused by simple sight. In all presented experiments more advanced sight system was not applied. That is why in the next experiments, the influence of double and dynamic sight was investigated. The values of parameters used in the experiments are as follows:

- Cost of motion dependent on speed – FALSE;
- Dynamic sight – TRUE;
- Double Sight – TRUE;
- Punishment for collision – 50;
- Distance to attack – 5;
- Distance to eat plant – 5;
- Distance to collision – 5.

Unfortunately, this experiment, like the previous one, does not result in flocking behaviour. On this basis we can conclude that the building of sight system of animals has no influence on their flocking behaviour. But more probable is that the proper sensor system is one of many elements that should be present in order to breed flocking behaviours.

4.4 Steered evolution

All experiments described so far have disclosed a weakness of the `Flock` system. The simulated artificial world does not contain sufficient mechanisms, that would stimulate flocking behaviour. In the next experiment we try to search for the reason of this problem. The system has been modified in this way that individuals were rewarded for staying close to other animals from the same species. This solution represents an approach applying steered evolution (the parameter *reward for staying close to the other organisms from the same species* set to TRUE), because the fitness function will reward individuals for concrete desired behaviour. In this experiment all plants were removed from the world. The only way to increase herbivore energy was staying close to other herbivores. The increase of animal energy in each time step was equal to the number of individuals of the same species being present in the sight radius of this individual. The parameters were set as follows:

- Number of plants – 0;
- Cost of motion dependent on speed – FALSE;
- Dynamic sight – TRUE;
- Double Sight – TRUE;
- Punishment for collision – 50;
- Distance to attack – 5;
- Distance to eat plant – 5;
- Distance to collision – 5.

This experiment showed more desired effects in comparison with the previous ones. Animals very quick gathered in small groups consisting of four individuals. It is no wonder since the main stress of fitness function was put on the decrease of distance between animals in our artificial world. The most frequently happened motion of animals is shown in Fig.14.

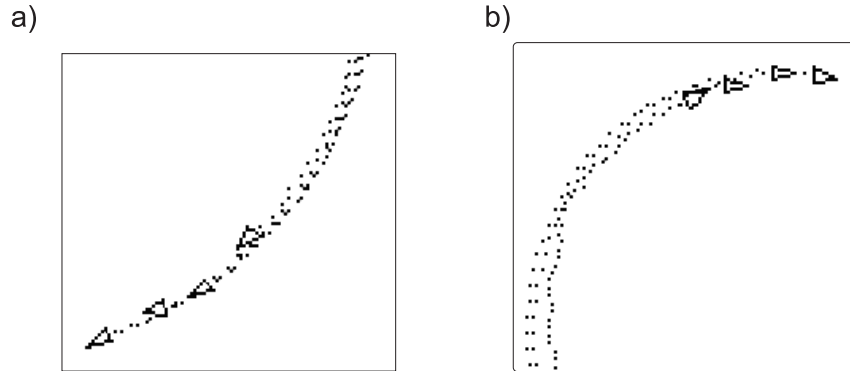


Fig. 14. Two examples of moving of herbivores in a flock

The observed results are very similar to those described by [16], but it is worth to mention that in our case the motion is not gross artificial, as it was in the cited paper. The motion of a group has been influenced of the passed objects, what caused that the group often changed direction of its motion. Therefore the formation of organisms motions may be listed here as the main weakness of the solution. The animals lined up, what resulted in motion that was similar to flocking of ducks running one by one. This experiment does not result in sufficient flocking behaviour however it confirmed the hypothesis formulated by [16]. They suggested that in order to achieve natural collective behaviour, a diversified environment is needed, in which the motion of flock will be modified by a set of stimuli.

Let us underline that the experiment was performed without plants. This may suggest that motionless objects are not essential elements for quality of behaviour manifested by herbivores. Much more crucial role play predators, mainly because they are moving objects. Predators manifested complex behaviour in this experiment also. Just like herbivores, they formed small groups moving together. The examples of their behaviour are shown in Fig. 15.

5 Conclusions and future works

In this work we tried to apply open-ended evolution to design controllers for artificial organism, which would be able to demonstrate flocking behaviours. In

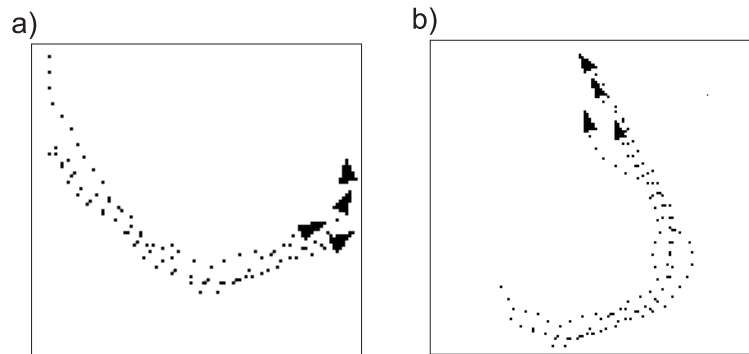


Fig. 15. Two examples of a group of predators moving in a flock

comparison to the previous works of other researchers the artificial world represented in our system was characterized by a diversity of organisms. Additionally, double and dynamic sight was introduced, which was suggested in the previous work in this area. All these attempts has the aim to breed flocking behaviours faithfully simulating the conducts existing in nature.

During performed experiments many different behaviours were observed. One of them were flocks. The observed motion of animals looked natural. The animals moved in groups reacting to the passed objects from the artificial world. To the full success, however, it was necessary to apply steered evolution.

Apart from forming a group by animals, many interesting behaviours have been manifested by the organisms. The escape of herbivore from predators, making herbivores way towards plants or a pursuit of predators after herbivores are the examples of basic reactions of animals observed during experiments. Another interesting behaviour was grouping of predators around plants, where the probability to meet herbivores is greater than in other places.

As the experiments have shown, the approach based on open-ended evolution has turned out to be insufficient solution to observe flocking behaviour. The problem in a such system is our poor knowledge about mechanisms managing flocking behaviour. The researchers are still not able to explain the reasons of forming such collective behaviour of species in nature. Therefore computer aided evolutionary simulation of this effect is still a great challenge.

Greater complexity of artificial world, where organisms can be developed stimulated by various stimuli, may be pointed out as further works in this area. Unfortunately, such solution has its own weakness. It increases the complexity of the system and results in difficulties in tuning the parameters of the system. But as suggest our experiments, the increase of diversity of simulated world in a connection with steered evolution seems to be a good solution for that purpose.

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