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An Emotion Model for Predator-Prey Bird Behavior

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Abstract

One of the main objectives of artificial intelligence lies in the simulation of the behavior of living organisms; emotions are a fundamental part of life, and they cannot be left aside when simulating behavior. In this research, software is developed that simulates the behavior of birds with different characteristics. The latter interacts by considering different stimuli from the environment (external), and the internal state of the subject (objectives). To achieve this, a model of birds in the role of prey and predators is developed that focuses on the study of the interaction between these organisms that exhibit specific behaviors in their environment. This project is a seminal work that aims to represent the emotions of birds, and the latter caused by stimuli from a dynamic environment.

Keywords

Predator-Prey Bird Behavior, Affective-Cognitive Structure, Computer Simulation Multi-Agent Systems, Mental Models

1. Introduction

In this research, the different reactions of prey and predator birds are explored, considering the specific characteristics of each one and its environment. This work has its beginnings in an experiment that was carried out with various types of pets (bird, turtle and dog) [1], where the foundations of emotions are laid as a consequence of the degree of consciousness that they can have according to their objectives and the stimuli coming from different environments. The above applies the five axioms of consciousness of Igor Alexander [2].

The software is based on the artificial intelligence stream, where the *Multi-*

Agent Systems (MAS) paradigm is used to simulate the interaction between birds. The above is to achieve intelligent behavior coordinated between a collection of autonomous agents. The latter coordinate their knowledge, objectives, skills, and plans to execute an action or solve a problem [3]-[5] related to the interaction of birds with their environment, including within this, other birds of their species and other species. The bird flight behavior algorithm is based on the flocking algorithm used in bird simulation, which was enriched by including emotions and different roles in bird behavior [6].

This project focuses on exploring fields of study such as ethology and cognitive psychology, synthetic emotions, and MAS applied to the interaction between birds: prey and predators [6] [7].

According to [8], all behavior has motivation as its main driving force and this originates from various causes; one of them is emotions and these are the ones that determine processes as important as decision-making to show rational behaviors.

This research aims to provide an argument about the different circumstances and decisions that allow for better performance, according to the objectives of each subject.

To achieve this, the theory related to the cognitive structure of emotions is used as a theoretical framework, specifically the theory developed by Ortony, Clore, and Collins [9], known as the OCC Theory. This theory allows us to formalize the algorithms related to the emotions that intervene in a behavior that interacts with that of other organisms.

Given that affects are the cognitive representation of emotions and are underlain by substantial information that is considered in the decision-making process. It is important to consider it to represent the behavior of any animated organism.

2. Simulation of Behaviors and Their Environments

A simulation is a virtual representation of a real-world system or process using software and mathematical models. Its main objective is to imitate the behavior and interactions of the elements of the real system in order to study, understand or predict its operation in different situations.

Computer simulations are used to study the dynamic behavior of objects or systems in response to conditions that cannot be easily or safely applied in real life. Simulations are beneficial for allowing observers to measure and predict. This leads us to ask how the functioning of an entire system might be affected by altering individual components of this system [10].

Within this project, simulation not only allows the study of individual behavior of prey and predator birds, but also facilitates the observation of how these interactions are affected by factors such as the availability of food, shelters, and changes in the environment. Furthermore, using OCC Theory, it is possible to analyze how emotions influence the decisions and actions of the simulated birds.

3. Ethology of Prey Birds

From an ethological perspective, the behavior of birds of prey [11] has a series of strategies to survive in environments where they constantly face the threat of predators. Some key aspects of their ethology include:

- **Constant surveillance and alertness:** prey birds are continually in a state of vigilance, attentive to any sign of danger. Their senses of vision and hearing allow them to detect the presence of predators in their environment.
- **Escape behaviors:** when they perceive an imminent threat, birds of prey exhibit rapid and effective escape behaviors. This may include evasive flight, sudden changes in direction, or seeking refuge in safe locations.
- **Group behavior:** some species of birds of prey group together in flocks to increase early detection of predators and dissuade potential attackers with their numbers and coordinated behavior.
- **Shelter from bad weather:** prey birds exhibit an instinctive behavior of seeking shelter in adverse weather conditions. In the presence of bad weather, these birds seek refuge in protected areas. This behavior not only allows them to shelter from bad weather but also provides them with a safe place to minimize the risk of attacks by predators.

4. Ethology of Predatory Birds

Ethology is a science based on the observation of animal behavior to discern the objectives of their different behaviors in the environments. According to Charles Darwin "the mental difference between man and the higher animals, though great, is certainly one of scale and not of kind" [12]. Based on the above, it is considered that cognition focuses on acquiring knowledge and intelligence on the ability to apply it successfully.

According to [12], it is undeniable that humans are animals, so when we study the behaviors of other animals, we are not comparing separate intelligence but rather considering variation within a single category.

Based on the above points, the simulation experiment is based on considering bird cognition as a variant of animal cognition, which of course, includes human beings. From an ethological point of view, predatory birds [13] exhibit a unique set of strategies that allow them to capture prey and ensure their survival. Some important aspects of their ethology include:

- **Active hunt:** predatory birds are active hunters that actively seek out prey. They use hunting strategies, including flying at high speeds, diving from the air, or ambushing from elevated perches.
- **Strategic decision-process:** predatory birds must make strategic decisions about when and how to attack their prey. This involves assessing distance, flight speed and selecting suitable prey.
- **Increased competition due to the presence of other predators:** in response to the presence of other predators in their territory, some predatory birds may intensify their competition for resources and hunting areas. This may involve confrontations and aggressive competition for access to prey and territory.

5. OCC Theory

The OCC theory [9] is a cognitive psychology theory that focuses on understanding and studying emotions and how they affect decision-making and perception. It was developed by two cognitive psychologists and a cognitive science computer scientist Andrew Ortony, Gerald Clore, and Allan Collins in the 1980s. Figure 1 graphically summarizes the OCC Theory. For more information on the OCC Theory, consult the references included in this article.

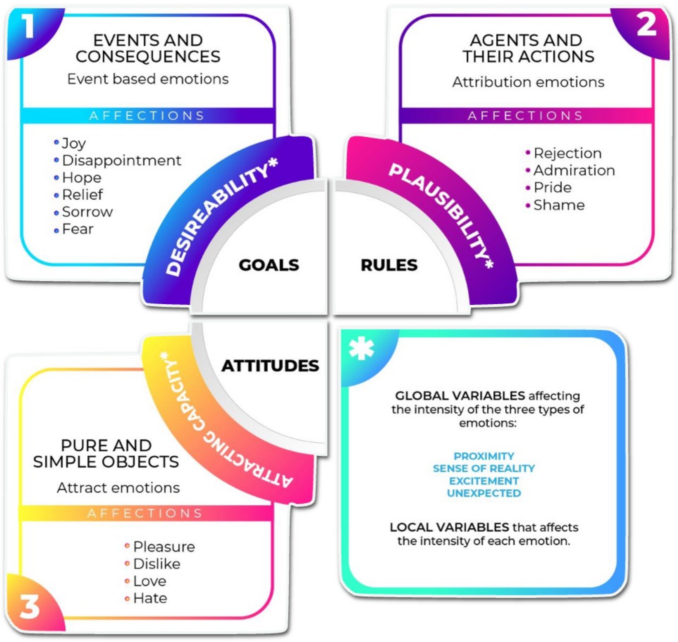

Figure 1. OCC Theory. Own elaboration, based on [9].

The assessment structure for decision making according to OCC Theory is made up of the following elements:

1) Macrostructure of assessment of the knowledge representation system.

2) Central/global variables that allow giving value to the logical object (events, agents, or objects).

The central variables of intensity (reactions) of the OCC theory are the following:

A) Desirability: the intensity of emotions about events correlates with the degree of desirability.

B) Plausibility (to abide or to violate): plausibility depends on the agent's effort or lack of effort (control of action, responsibility) to comply with or violate these norms, and may produce the actions listed below.

- Sin of omission (non-effort);
- Sin of commission (effort);
- Virtues of commission (effort).

C) Ability to attract: the ability to attract does not imply an understanding of its meaning (contrary to desirability, which considers consequences). This is why it is significant in emotions with low cognitive content.

The global variables used in OCC theory are:

A) Sense of reality: the degree to which the event, agent, or object underlying the affective reaction appears real to the person experiencing the emotion.

B) Proximity: attempts to reflect the psychological proximity of the event, agent or object that induces the emotion.

C) Unexpected quality: affects the control that one has over the environment.

D) Excitement: the previously existing level affects the intensity of the emotions.

Three types of goals are considered within this theory:

Active pursuit goals

- Achievement;
- Entertainment;
- Instrumental;
- Crisis.

Goals of interest

- Preservation (status quo).

Fill goals

- Of satisfaction (cyclical): physiological and routine.

6. Multi-Agent Architecture

Distributed artificial intelligence (DAI) is used for distributed problem solving. It consists of dividing modules that cooperate, and the knowledge about the problem is separated and/or shared between them [14]-[16].

Hence, intelligent behavior is achieved through coordinating their knowledge, objectives, skills, and plans to execute an action or complete a task.

Depending on the different forms of communication between agents, we have systems:

1) **Strongly coupled**, where communication takes place through a shared memory.

2) **Loosely coupled**, where communication is through message passing.

In this type of system, three factors influence the choice of a particular organization: (1) the complexity of the problem that involves the number of agents, (2) the imprecision and uncertainty, (3) the eventual existence of a decomposition of the problem. *In the case study, it was decided to use DAI given the complexity of the problem since it demands local points of view, which allow for a rapid transition between perception and action.*

Design based on a local view is a promising approach to solving complex problems. It is easy to obtain results by avoiding the difficulties of trying to solve a problem, that is, results emerge as a result of local interactions. Systems must be able to adapt to dynamic environments. In the context of a Multi-Agent system, it is assumed that reasoning is always local due to the inherent distribution. This allows agents to appear and disappear during execution.

The design of these architectures is influenced by the behavioral psychology theory Brooks, Chapman and Agree, Kelabling, Maes, Ferber, Arkin mentioned in [15]. This class of agents is also known as: (1) behavior-based, (2) located (immersive), and (3) reactive.

The dynamics of **action-selection** for this type of system emerges based on two basic aspects: (1) the conditions of the environment, and (2) the internal objectives of each agent. Its main characteristics involve dynamic interaction with the environment, and internal mechanisms that allow working with limited resources and incomplete information hence an **intelligent agent** can exhibit the following behaviors:

- **Proactive:** they are able to exhibit goal-directed behavior, taking the initiative to meet their goals.
- **Reactivity:** they are able to perceive their environment and respond in real time to changes that occur in order to meet their goals.
- **Social ability:** they are able to interact with other agents, possibly human, in order to meet their goals.

According to [16]-[19], a Multi-Agent system contains several agents with the following characteristics:

- They interact through communication.
- They are capable of acting in the environment.
- They have different spheres of influence, that is, they may or may not coincide.
- They are linked to each other in an organized way.

7. Project Development

The project consists of three essential modules that are described below and their operation is summarized in Figure 2.

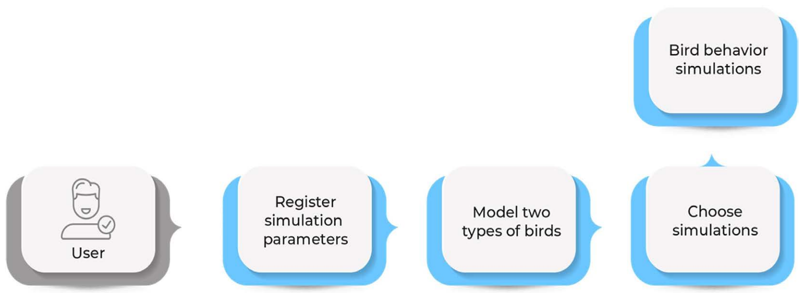

Figure 2. Use case diagram.

Capture module: this module is responsible for obtaining the simulation parameters that will be entered by the user, such as the number of birds, the environmental conditions and the type of prey or predator birds present in the simulation.

Representation tools module: this module is responsible for modeling the interaction of *prey and predator birds* in the environment that surrounds them. OCC theory is used to represent the decision-making of birds regarding their behavior based on the information perceived in the capture module. It is also responsible for defining and executing the specific behaviors of the agents in response to the decisions made using the flocking algorithm.

Simulations module: its main function is to graphically show, through simulations, the interaction of prey and predator birds based on the model established in the representation tools module.

Technical Specification

The project was developed in *Java* using the *Processing* IDE, which is specifically designed for creating interactive design projects, as it provides predefined functions and classes that allow working with images, sound, animations, vector graphics, and other visual elements. In addition, *Processing* allows you to run projects directly in the IDE, which facilitates quick visualization of results. To address the different use cases, the project consists of the following modules:

- **Capture module:** it allows you to record the desired parameters for carrying out the simulations. The number of birds (both prey and predators), the climate and the amount of food and shelter present in the environment.
- **Representation tools module:** it models the different birds, their behaviors, and the environment that surrounds them according to the parameters established in the capture module. Through the *P Vector* class provided by *Processing*, we can calculate the distances between the birds, their direction in case they join a flock, as well as the behaviors they will adopt according to any of the following situations: **a) repulsion:** prevents the birds from colliding, **b) alignment:** allows the flock to move in the same direction, and **c) cohesion:** allows them to approach the center of the group.

In the **case of the predator**, algorithms were used to model its behavior in front of prey. An area is defined in which a sign of nearby prey is randomly searched for. The situation is then analyzed in order to determine the possibility of attacking the prey (in a flock or alone). This allows the pursuit and capture of the prey to begin.

- **Simulation module:** it allows the results of the simulations and the interaction of the birds to be graphically displayed based on the parameters recorded in the capture module. In addition, within the simulation, more birds can be added or subtracted in the role of prey or predators, in order to observe their behavior.

8. Mental Models

According to [20], a cognitive model comprises the point of view of the animal behavior in question within its environment and is limited to a specific activity. Hence, the formality of mental models to be able to recreate reactive behavior through precise algorithms. Mental models allow us to represent the behaviors we want to incorporate in the different systems involving artificial intelligence. In the case study, we refer to the behaviors of birds in their two roles as predator and prey.

In this work, a mental model corresponds to a certain behavior that will come into action when a stimulus is presented, allowing it to interact with the dynamic and random environment on any given day. These mental models are algorithms represented through control structures and first-order logic.

In some cognitive areas, it is possible to formulate theories of competence, which specify what has to be calculated, when, and why. Later, based on these theories, develop an algorithm that represents it. This area of study is known as the theory of competence and is carried out based on mental models.

8.1. Prey Bird

The behavior of the bird-prey is represented by two mental models that characterize its conduct.

1) *Surviving*, represents the main behavior (**Figure 3**).
2) *Satisfying Needs*, is a complementary behavior (**Figure 4**).

```
WHILE (Alive == True)
    IF (Predator Exists == True and Danger is nearby == True)
        Feels Fear
        Feels Worried
        Feels Anxious
        IF (Flock is nearby == True)
            Attempt to Join Flock
            IF (Successful Joining == True)
                Feels Relief
                Feels Safety
            END_IF
        ELSE
            Attempt to Escape
            IF (Successful Escape == True)
                Feels Relief
            ELSE
                Alive=False
            END_IF
        END_IF
    ELSE
        Satisfying Needs
    END_IF
END_WHILE
```

Figure 3. Survive.

```
IF (Normal Weather == True)
    IF (Hungry == True)
        Feels Anxiety
        Search for Food
    END_IF
    IF (Has Flock == False)
        Search for Flock
    END_IF
    IF (Hungry == False and Has Flock == True)
        Feels Satisfaction
        Feels Security
    END_IF
ELSE
    IF (Has Flock == False)
        Feels Anxiety
        Seek Shelter
    END_IF
```

Figure 4. Satisfying needs.

Six emotions are related to this behavior, which will be reflected in the affective-cognitive structure (**Figure 5**). These are: 1) fear, 2) anxiety, 3) relief, 4) satisfaction, 5) worry, 6) security.

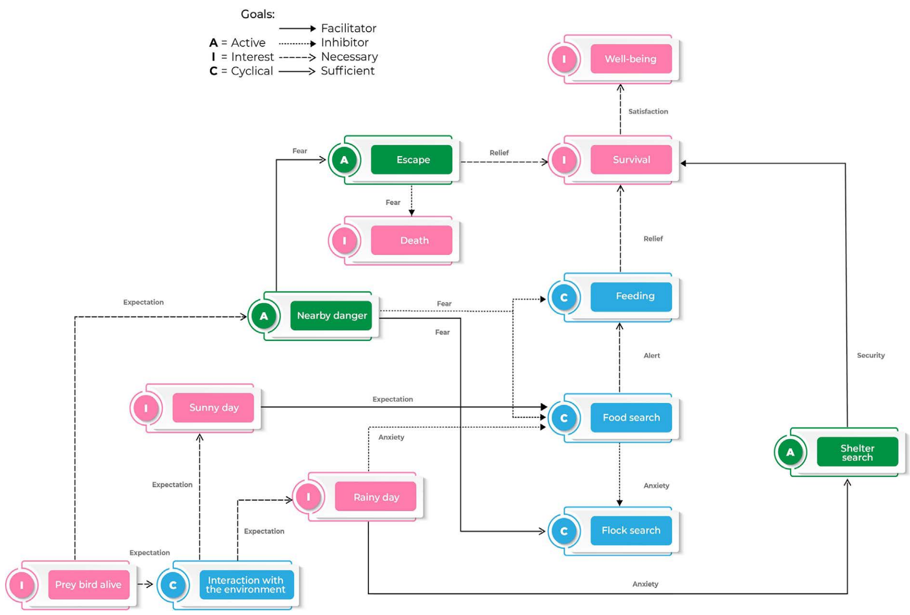

Figure 5. Affective-cognitive structure of the pray bird.

8.2. Predatory Bird

The behavior of the predatory bird is represented by three mental models that characterize its conduct.

1) *Daily*, represents the main behavior (Figure 6).
2) *Hunting*, is a complementary behavior (Figure 7).
3) *Facing Predators*, is a complementary behavior (Figure 8).

```
WHILE (Alive == True)
    IF (Normal Weather == True)
        Hunting Behavior
    ELSE
        Feels Anxiety
        Feels Frustration
        Slow Wandering
    END_IF
```

Figure 6. Daily.

```
WHILE (Other predators nearby == True)
    Increased Competition
    Facing Predators Behavior
END_WHIL
```

Figure 7. Hunting behavior.

```
IF (Hungry == True)
    Feels Anxiety
    Feels Aggression against Predators
    IF (Successful Capture == True)
        Feels Satisfaction
    ELSE
        Feels Frustration
    END_IF
ELSE
    Feels Satisfaction
    Slow Wandering
END_IF
```

Figure 8. Facing predators behavior.

Four emotions are related to this behavior, which will be reflected in the affective-cognitive structure (**Figure 9**). These are: 1) anxiety, 2) satisfaction, 3) frustration, 4) aggression.

Based on what was explained in Sections 5 and 6, the affective-cognitive structure of the two roles of prey-predator birds is elaborated. They are represented in **Figure 4** and **Figure 9**, respectively.

9. Multi-Agent System

In this project, a Multi-Agent structure is implemented that effectively represents a dynamic virtual ecosystem. This system includes multiple agents represented in each of the roles: prey-predator birds, food and shelters. Through the interaction of these agents, a precise and detailed representation of the behaviors and relationships between the different entities in the simulated ecosystem is achieved.

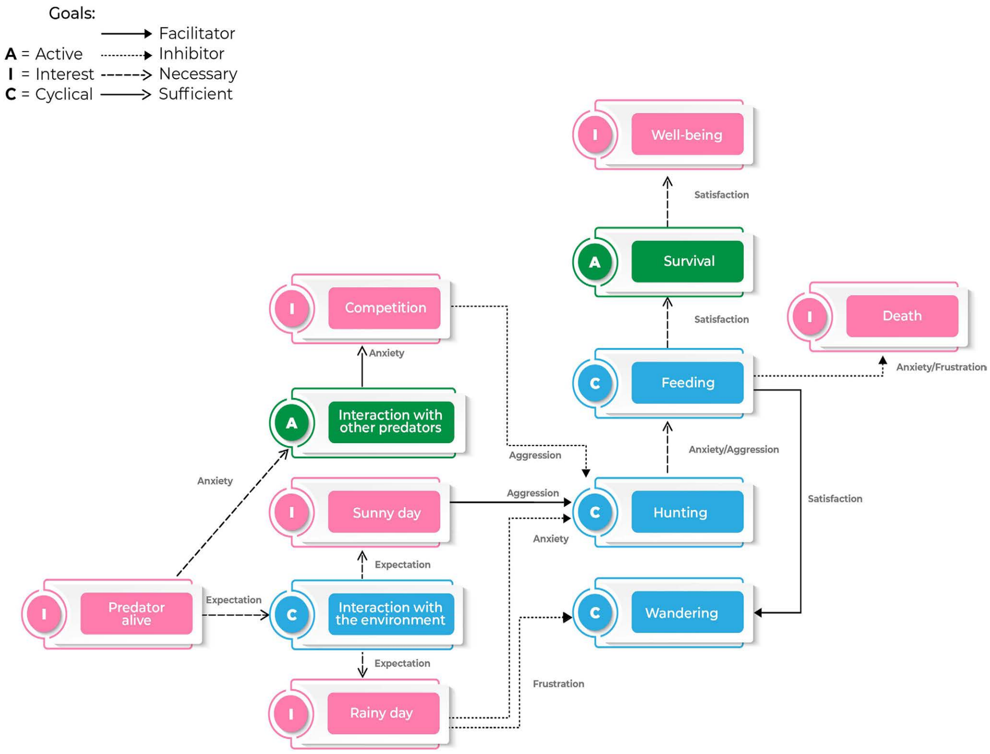

Figure 9. Affective-cognitive structure of the predator bird.

Prey birds: birds of prey seek to survive in the simulated environment. They have behaviors such as searching for food, shelter, and flocks to increase their probability of survival. In addition, they are programmed to detect the presence of predatory birds and take evasive measures when they are in danger. They are represented by the following agents:

- *Update* (*update*): responsible for updating the position of the bird within the environment and its behavior.
- *Safe* (*is Safe*): responsible for verifying whether the bird is safe from predators, either because it is within a flock or within a shelter.

- *Hide* (*hide*): responsible for the bird seeking shelter when it detects bad weather and is not in a flock.
- *Hungry* (*is Hungry*): responsible for reducing the bird's food level over time.
- *Eat* (*eat*): responsible for increasing the bird's food level by eating.
- *Display* (*display*): responsible for showing the bird on the screen.
- *Display Emotions* (*display Emotions*): This is responsible for displaying a bird's emotions on the screen if selected.

Predator birds: they are the hunters of the ecosystem. Their main objective is to search for and hunt pray birds. Their behavior is based on the detection of prey, hunting and competition with other predatory birds for available resources. They are represented by the following agents:

- *Update* (*update*): is responsible for updating the predator's position within the environment and its behavior.
- *Hungry* (*is Hungry*): is responsible for reducing the predator's food level over time.
- *Feeding* (*eat*): is responsible for increasing the predator's food level by eating. Display (display): is responsible for showing the predator on the screen.
- *Display Emotions* (*display Emotions*): Displays a predator's emotions on screen if selected.
- *Display Status*: (*display Sstat*): If enabled by the user, displays relevant information about its internal state (food level, speed, competency, and whether it is hunting or roaming).

As for the environment, this is represented by food; these are essential resources for the survival of birds of prey. *Refuges* are safe areas where prey birds can hide from predators; they offer a place for birds to protect themselves and recover from risky situations.

The Multi-Agent structure allows for dynamic interaction between these agents. Prey birds seek food and shelter, while predatory birds hunt and compete with each other.

Prey birds may also seek the safety of shelters and form flocks to increase their collective protection.

Each agent follows a set of rules and behaviors defined according to its function to show coherent behavior of birds in the ecosystem. That is, predatory birds may follow hunting strategies, while prey birds may have evasion patterns in response to the presence of predators. They are reactive agents interacting with a dynamic environment.

10. Examples of Artificial Ecosystem

The main menu is shown below, where the initial parameters for performing the simulations will be obtained (**Figure 10**).

This menu uses two sliding scales, better known in the computer field by their term in English sliders, to determine how many birds of each type will be initially found in the simulation. Where there can be a maximum of 100 prey birds and a maximum of 5 predatory birds. It also has three drop-down lists of options, better known in the computer field as combo boxes, where the parameters are determined: a) climate (sunny-cloudy), b) number of shelters: none, few (from 1 … 4), normal (from 5 … 8) or many (from 9 … 12), and c) amount of food that will exist at the beginning of the simulation: none, little (from 20 … 30), normal (from 31 … 40) or a lot (from 41 … 60). These will be displayed as a value is selected for each parameter, at the end a button will be displayed to start the simulation (Figure 11).

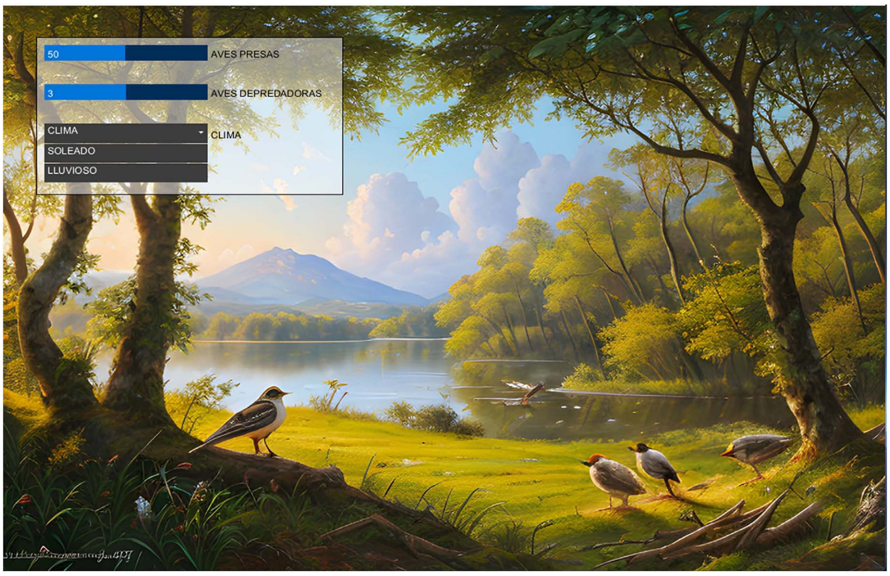

Figure 10. Main menu.

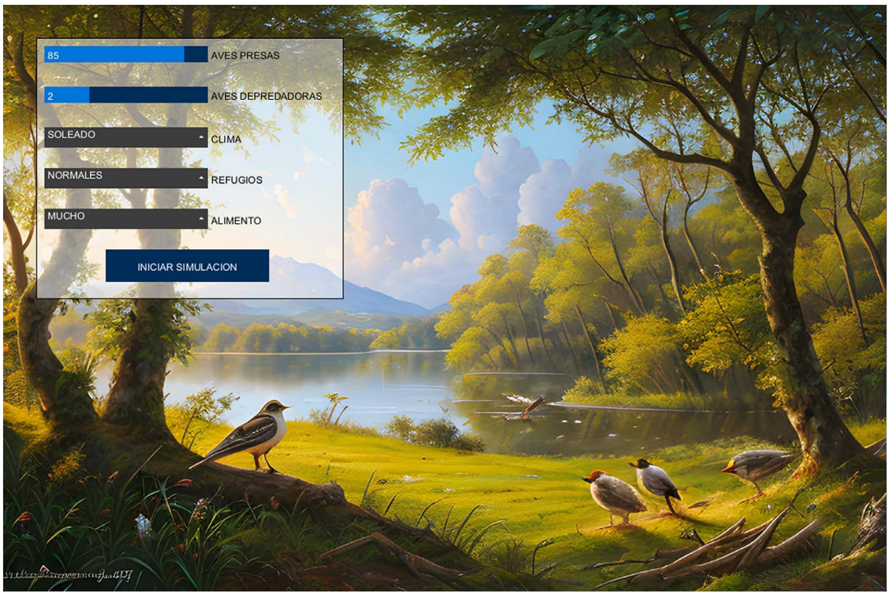

Figure 11. Main menu with selected parameters.

The following images are used to simulate the flight of predatory birds (Figure 12).

Figure 12. Movement of predatory birds.

The following arrangement of images is used to simulate the flight of birds of prey (Figure 13).

Figure 13. Bird-prey movement.

Shelters, food and rain were represented in the program with the images shown in Figure 14.

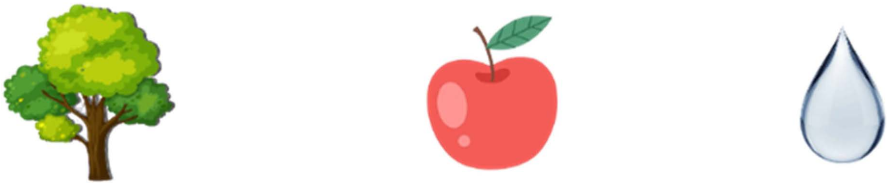

Figure 14. Elements of the environment.

During the execution of the program, one can have an environment with a sunny day, or a rainy day as shown in Figure 15 and Figure 16, respectively.

Figure 15. Sunny day.

Figure 16. Rainy day.

While it is raining, predatory birds remain wandering around, while prey seek to feel safe, either by staying in a flock or by seeking shelter, from which they will leave to return to their natural behavior once the rain has stopped, as shown in

Figure 17.

Figure 17. Prey birds leaving the refuge.

Certain statistics for predator birds can be displayed, such as their food level, speed, whether or not they are competing, and whether they are hunting or roaming, as shown in Figure 18.

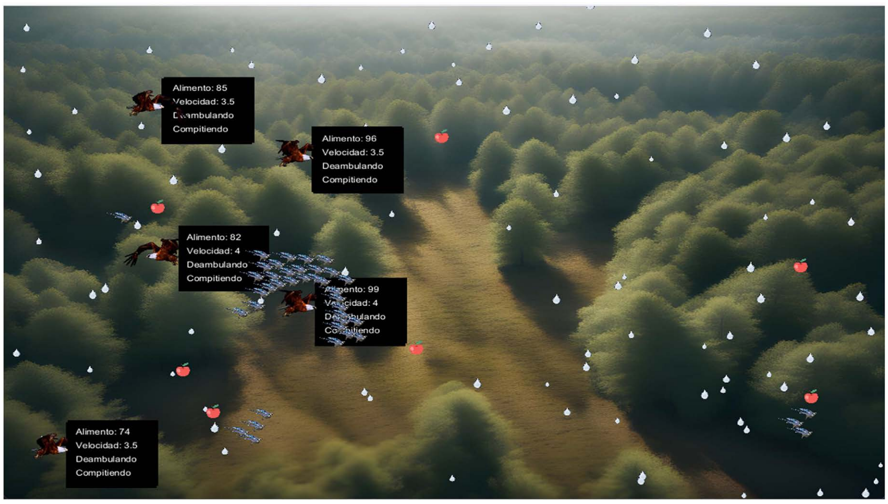

Figure 18. Predator Statistics.

When starting the program, a box is also displayed in the upper right corner that indicates general information about the simulation, such as the number of prey birds that have been hunted by predators, how many have starved to death, or how many predators have starved to death as shown in Figure 19.

It is also possible to check the emotions felt by both prey and predatory birds at any time with the left mouse button, as shown in Figure 20 and Figure 21, respectively.

Figure 19. Simulation statistics.

Figure 20. Emotions of a prey bird.

11. Analysis and Discussion of Results

During the simulation development, we encountered several challenges that required ingenious solutions. One of the initial obstacles was the design of the classes and objects that would represent the birds in the simulation. To solve this, we carried out an exhaustive class design, defining the properties and methods needed for each one; which corresponds to the multi-agent architecture that represents the different elements (agents) that make up the behavior of prey and predator birds; as well as their environment.

Interactions between birds also presented a challenge, as we had to manage how prey birds responded to the presence of predators or the weather, and how predators hunted or competed when they were close to each other. Establishing clear rules for these interactions turned out to be essential.

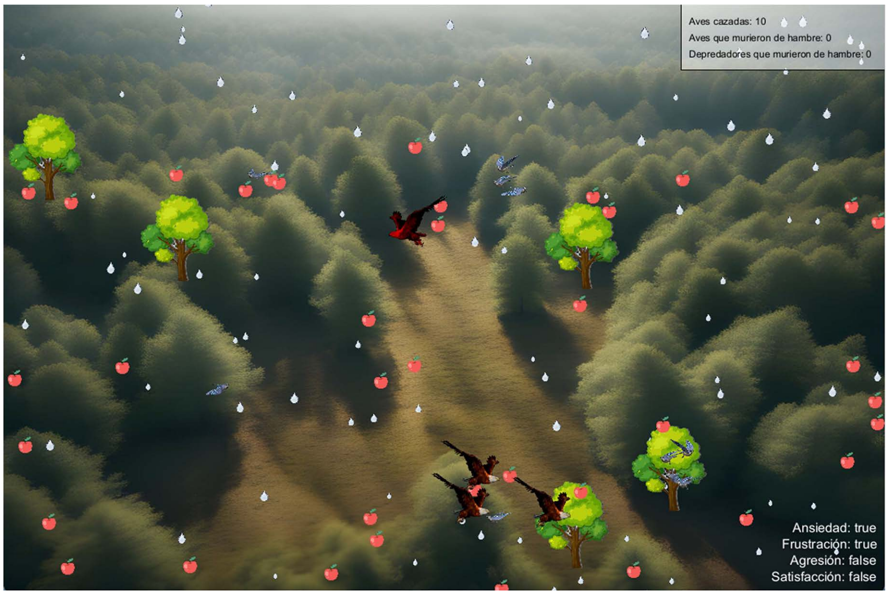

Figure 21. Emotions of a predatory bird.

Another problem that arose was the logic behind knowing when behaviors such as searching for food or shelter should occur. To do this, we relied on our mental models and affective-cognitive structures to determine which emotions led to the execution of these behaviors.

Performance also became a concern as the simulation grew in complexity and size. To optimize it, we applied techniques such as eliminating unnecessary calculations and using efficient data structures.

This program could be used as a basis in the future to be explored with circumstances that were not considered for this specific program. Examples could be: bird reproduction, different ecosystems and climates, specific bird species, etc.

Simulated Scenarios

Within this project, it is considered that every 50 seconds of real time are equivalent to one day within the simulation. Another consideration is the level of food for each bird, which has a range from 0 to 100, where the value 100 represents that the bird is completely satisfied and, if it reaches the value 0, the bird dies of hunger.

At the beginning of the simulation, initial parameters such as shelters and food are randomized within a specific range.

For shelters:

- None. 0;
- Few. 1 to 4;
- Normal. 5 to 8;
- Many. 9 to 12.

For food:

- None. 0;
- Few. 20 to 30;

- Normal. 31 to 40;
- Many. 41 to 60.

According to bird ethologies [15] [17] [18], prey birds, needing less energy to survive than predators, increase their food level more each time they eat, and they also spend less energy. For these reasons, within the program, a prey bird, assuming it starts with a food level of 100, can survive 2 days (100 seconds in real time) until its food level reaches 0 and it dies of hunger. Prey birds will make searching for food their main priority once their food level reaches 50. This is because they must separate from their flocks to feed themselves, thus exposing themselves to attack by a predator, and they would have enough time within the simulation (1 day) to find food.

On the other hand, predators need more energy to survive, so their food level decreases from 100 to 0 in the span of a day (50 seconds in real time). For these reasons, predators begin actively foraging (hunting for prey) once their food level reaches a value of 70. Assuming a predator starts with a food level value of 100, it would take about 8 hours within the simulation to begin actively foraging (15 seconds of real time).

Taking into account the above, below are 3 simulated scenarios within the program:

First scenario: for the first scenario we started the simulation with 50 prey birds and 3 predator birds, with no shelters and little food. After 1 minute and 50 seconds of real time (2 days and 5 hours into the simulation as shown in **Figure 22**), the predator birds had already hunted half of the prey birds.

Figure 22. First scenario after 2 days and 5 hours.

After 3 minutes and 40 seconds of real time (4 days and 10 hours within the simulation as shown in **Figure 23**) all the prey birds had been hunted, except for one that died of starvation. This may be because, without shelters in the environment, it was easier for prey birds to be hunted by predators, and because, as the number of prey birds decreased, there was less competition for food that appeared in the environment.

Second scenario: the simulation begins with 100 prey birds and 1 predator bird, few shelters and no initial food. After 1 minute and 30 seconds of real time (1 day and 20 hours within the simulation represented in Figure 24), the predator birds had hunted 7 prey birds, while another 43 had died of starvation.

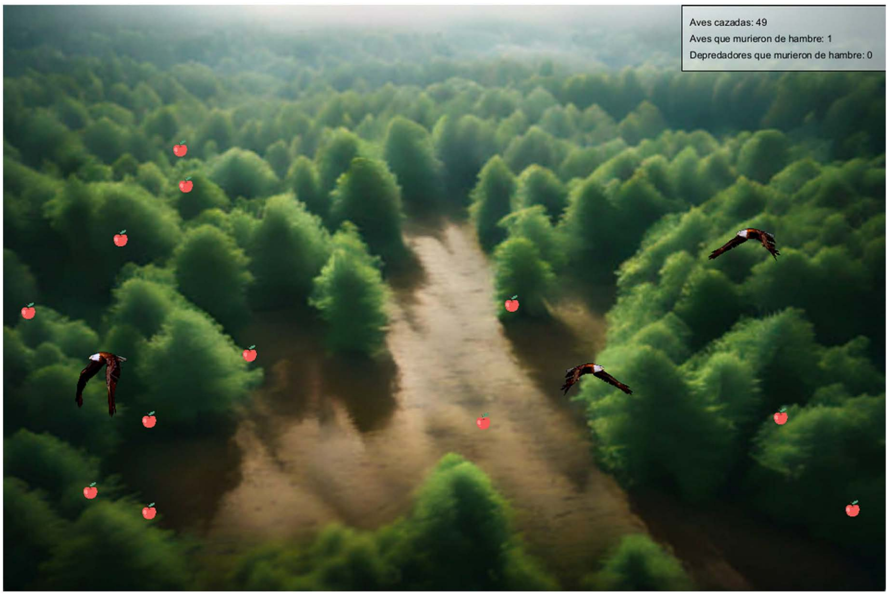

Figure 23. First scenario after 4 days and 10 hours.

Figure 24. Second scenario after 1 day and 20 hours.

This is because the initial number of prey birds was too high for all of them to survive, considering that there was no food in the environment at the start of the simulation. It can also be seen that, as there was only one predator, not as many birds had been hunted, which leads us to assume that, in a scenario with more predators, the number of birds that died from being hunted and those that died of hunger would have been more balanced.

After 5 minutes and 10 seconds of real time (6 days and 5 hours within the simulation as we can see in **Figure 25**) all the prey birds had died. It can be seen that the time between the first half of the prey birds dying was much longer compared to the second half. This is because they were not as threatened by predators as in other scenarios, since there was only one in the simulation, and because there was less competition for food that was appearing in the environment, there was a greater chance that any bird could feed. This is demonstrated by the values represented in the simulation, where 78 birds died of hunger and only 22 were hunted.

Figure 25. Second scenario after 6 days and 5 hours.

Third scenario: for the third scenario we started the simulation with 25 prey birds and 5 predator birds, normal shelters, and plenty of food. After only 25 seconds of real time (12 hours within the simulation shown in **Figure 26**), the predator birds had already hunted half of the prey birds. After 1 minute and 10 seconds of real time (1 day and 10 hours within the simulation that we can see in **Figure 27**) all the prey birds had been hunted. This result was expected, since the initial number of prey birds was even smaller than the initial amount of food, so it was not expected that any bird would die of hunger. It is worth noting the speed with which all the birds died, because the number of predators was so high that it was reasonable to think that they would hunt relatively quickly such a small number of prey birds.

It is worth mentioning that, within each simulation, predators will begin to starve once there is no more prey in the environment, so this project could be expanded with new functionalities such as reproduction between entities to obtain more extensive simulation results.

Figure 26. Third scenario after 12 hours.

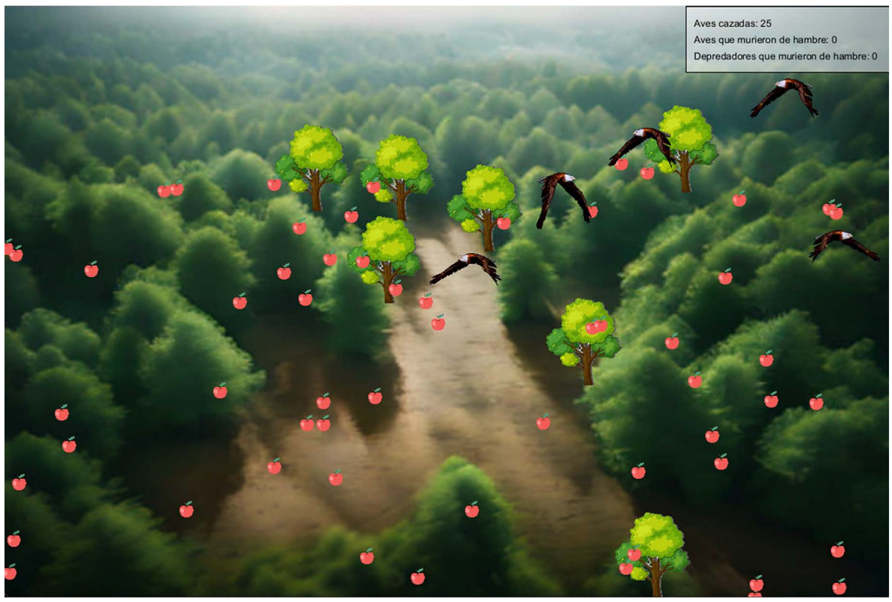

Figure 27. Third scenario after 1 day and 10 hours.

12. Conclusions

The behavior of birds of prey and predators was successfully represented in an environment with different characteristics using various graphical tools to demonstrate the results of the simulation.

Managing the interaction between prey and predator birds has required the definition of clear rules to achieve realistic and predictable behaviors. This involved the implementation of detection and decision-making systems that contributed to the authenticity of the simulation.

The simulation of the behavior of birds of prey and predators represents a significant achievement in the creation of a realistic and functional virtual environment that can be applied in various contexts for studying and analyzing bird behavior in their natural environment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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