Multi-Agent Formations in a Herd of Wolves Hunting Model

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***Abstract*-- A great amount of work has been made in systems of multiple autonomous agents and robots; for example, in applications like the exploration of land and harvesting of dangerous materials [12]. In this work we present a multi agent formation model of a herd of wolves during a prey-predator hunting behavior. The model has been developed and tested in a multi-agent simulation environment.**

I. Introduction

Much research in autonomous agents is inspired in social behaviors of animals. Examples of these are "animats" [5], which are artificial organism who live, feed, mate and die in a virtual world. These models can be both simulated as well as tested in real environments.

The application areas of multiple agents are quite diverse, such as agents that play soccer, military tasks and biological models of animal behavior like: ants, mantis, fish, frog, bees among others. In the biological domain, modeled behaviors include biological societies with the ability to flock, disperse, aggregate, forage and follow trails [8]. Here we can observe how cooperation emerges as a result of selfish interest.

In nature it is common to find formations in large group of animals, such as bird flocks and fish schools. Some of the benefits in grouping involve minimizing the encounters with predators [9][11]. Group behavior emerges from the desire to stay close to the group and, at the same time, keep a certain distance with others members of the group [3].

The behavior of an agent is defined by the information that it receives and the actions it takes. The connection that exists between perception and action is known as a condition-action rule [10]. We model agent behavior in our hunting application by means of finite state automata. The model consists of a group of wolves that hunt one or several preys in the field, in observing two crucial aspects in multi-agent systems: collaboration and formation. In addition to group formation benefits, agent groups collaborate for a common interest or reward, requiring a common communication form and language [13].

In terms of competition, examples of prey-predator models can be found in Greenbank [6] and Dolan [4]. Both of these show models considering emotional variables responsible for tiredness, hungriness, etc. with predators hunt alone without cooperation between them.

II. Hunting Model

The model is based on the wolf's hunting behavior (see figure 1). Unlike real wolves, our model considers a team of predator consisting of one *alpha* wolf and at least one *beta* wolf. Another difference with the real model is that the tiredness factor is not considered. In the real world, wolves keep a certain order to eat the captured prey [9], where the stronger eats first; however, this kind of behavior is not included in our model.

The following are the most important assumptions for the model:

a) Preys and predators can only receive visual information from the environment. Any other type of communication between agents is not allowed.
b) Agents use omni-directional vision in order to compensate for the lack of both hearing and smell.
c) Wolf teams will be conformed by a group leader (alpha wolf) and at least one follower (beta wolf).
d) Each agent taking part in the model will have to be able to determine its position and distances to other agent or object.
e) The formation of the group of wolves is defined by a relative distance to the alpha wolf, taken from a center defining a circumference where beta wolves will locate (see figure 2).
f) When a beta wolf moves outside the circumference it is linearly attracted back to the circumference; the more it moves away from the designated circumference, the greater it will be the attraction to get back.

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Figure 1. Herd of wolves.

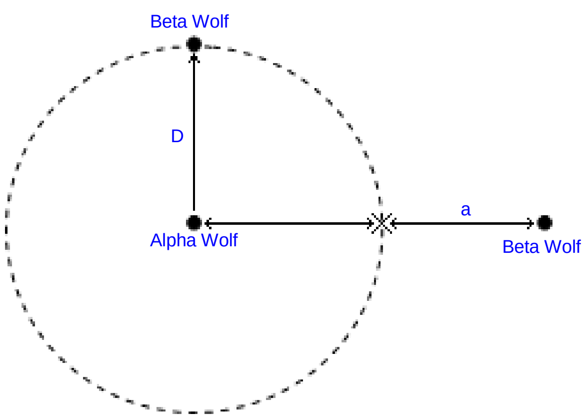

Figure 2. Formation circumference.

A. Predator Behavior

With the purpose of maintaining decisions simple, agent behaviors are described by the following basic rules:

a) Predators follow the leader within a certain distance when no preys are detected.
b) Predator speed is less or equal, in the best case, to that of preys.
c) When detecting a prey, predators follow the prey until catching it.

In the predator's team it is necessary to make a distinction between alpha and beta wolves. The first wolf is the leader and it is the one that sets the direction that the rest of the team will follow. The beta wolves only follow the alpha wolf (in absences of preys) keeping their distance.

1) Alpha wolf

The alpha wolf behavior is determined by three states: Wander, Hunt and Eat (see figure 3):

- <u>Wander</u>. In this state the alpha wolf explores the environment looking for a prey to eat. When it detects one, the *visible prey* condition is activated indicating a change to the following state (hunt). The calculation of the wolf movement is in terms of a magnitude and direction, a "1" and a number between 0 and 2π, respectively.
- <u>Hunt</u>. In this state the wolf follows the prey until catching it, or being close enough to the prey (less or equal to 6cm in our model). When this happens the *prey not visible* condition is activated and the agent changes to the Eat state. In this state the displacement direction of the wolf will be equal to the position of the target, where the magnitude is computed by the following equation:

$$magnitude = \begin{cases} 0 & , r > C \\ \dfrac{r-D}{C-D} & , D < r \le C \\ \infty & , r \le D \end{cases}$$

  In the equation r is the distance from the robot to the goal, i.e. the prey, C is the "controlled" zone, i.e. the area where the robot will slow down, and D is the "death" zone, i.e. the area where the robot will eat the prey.
- <u>Eat</u>. In this state the wolf stays near the prey while eating it; after that, the condition of *prey not visible* is activated indicating that the prey has been eaten. Here the agent motion is zero.

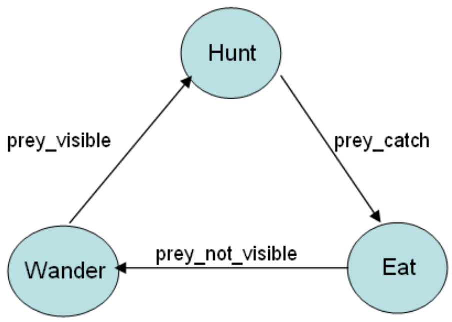

Figure 3. Alpha wolf behavior.

2) Beta wolf

The beta wolf position is determined by the leader position in almost all of the five states that conform the behavior of this agent, as explained next (see figure 4):

- Wander. The beta wolf searches the environment looking for the group leader; once it finds it, the *leader visible* is activated continuing to the next state (formation). The wolf movement is similar to the alpha wolf in this state.
- Formation. While the beta wolf continues seeing the alpha wolf, the agent stays close to the leader. If visible contact is lost with the group leader then the condition *leader not visible* is activated continuing to the Wander state. On the other hand, if the agent still sees the leader and detects a prey then the agent goes to the Stalk state while the condition *prey visible* is activated.
- Stalk. In this state three transitions can happen: one towards the Formation state in case the prey is outside its range of vision activating the *not visible prey* condition; another one occurs when it detects the prey close, this activates the condition of *prey near* continuing to the Hunt state; finally, in case the agent looses track of the alpha wolf, it executes the condition *not visible leader* and continues to the Wander state. The objective of this state is to approach the prey without separating much from the group leader.
- Hunt. The beta wolf considers itself sufficiently close to the prey; but still taking into consideration the relative position to the leader. Yet, in this state the move to approach and catch the prey has greater priority than follow the group leader. Nevertheless, because the prey is faster it is possible that the prey could escape. If this happens it activates the condition *prey far* and the agent is returned to the Stalk state. If the wolves manage to catch the prey, the condition *catch prey* is activated continuing to the Eat state.
- Eat. This state is similar to the alpha wolf.

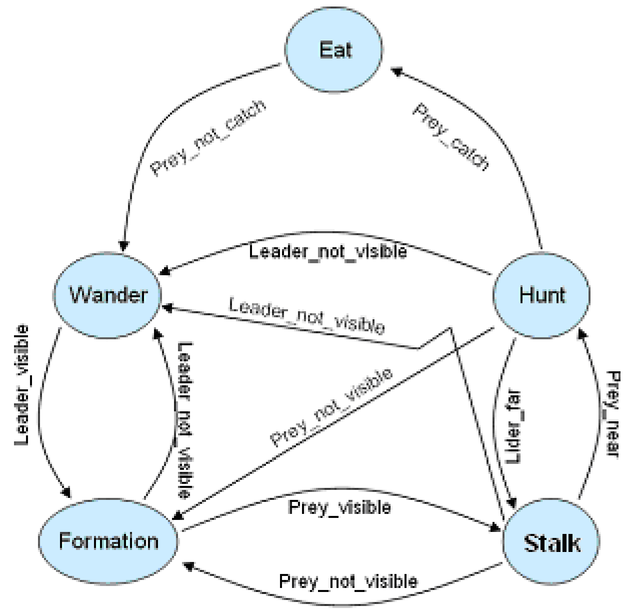

Figure 4. Beta wolf behavior.

B. Prey behavior

Behavior's prey is defined by five states: Wander, Recollect, Storage, Escape and Die. Unlike the predators a single type of prey exists. The transitions between the states are explained as follow (see figure 5).

- Wander. This state is similar to the alpha wolf's Wander state. The main difference is that the preys look for food and when a predator is in its sight the condition *predators visible* activates making the prey change to the Escape state. On the other hand, if the prey sees the food the *food visible* condition is activated continuing to the Recollect state.
- Recollect. The prey has seen food and takes it; activating *get food* and switching to the Store state. When it detects a wolf it goes to the Escape state with the transition w*olves visible*.
- Store. The prey has acquired the food and is ready to take it to its nest or base for storage; when it arrives there it activates the base transition *base near*. After that it goes back to the Wander state. If the prey detects any wolf, the transition to *wolf near* is activated and it goes to the Escape state.
- Escape. In this state there are two possible transitions, if the prey manages to escape, i.e. the prey can not see any wolf inside its line of sight, then it activates the transition *not visible wolves*, going to the explore state. In case that it could not escape and a wolf is sufficiently close, then the *bite* transition is activated and it goes to the die state.
- Die. Once the agent arrives to this state it will remain in it. It will not move again and it will not be considered a prey any longer.

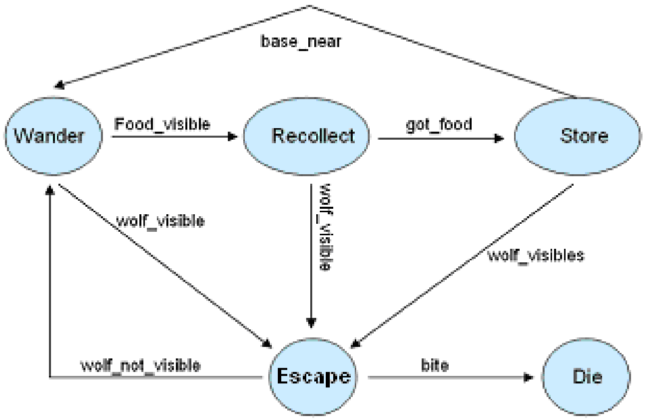

Figure 5. Prey behavior.

III. SIMULATIONS AND RESULTS

Several simulations of the model were made using different scenarios to observe the behavior of the wolves and the state of their formation during hunting. We evaluated model aspects such as: if the distance from beta wolves to the leader of the group stays constant; if the movements of one of the wolves does not interfere with the movement of some of the other wolves. Three basic scenarios were considered for this purpose:

- First, one having only predators, increasing their number to see how it affects group formation.
- Second, observing the hunting behavior when there is only one prey in the environment, while varying some parameters, such as velocity, to observe their effect.
- Finally, a more realistic environment was set up where agents (both preys and predators) wander about the environment in search for food.

In the first scene there are several obstacles in the field affecting the performance of the wolves in the formation since they must avoid or detour around them, moving away from the group leader in some case, while risking losing track of their leader and separating from the group.

An interesting result from these experiments is that beta wolves change their relative formation in relation to changes in the total number of beta wolves. With a small group of beta wolves the group results in a "v" formation as shown in figure 6, but when there are four beta wolves this formation changes as show in figure 7.

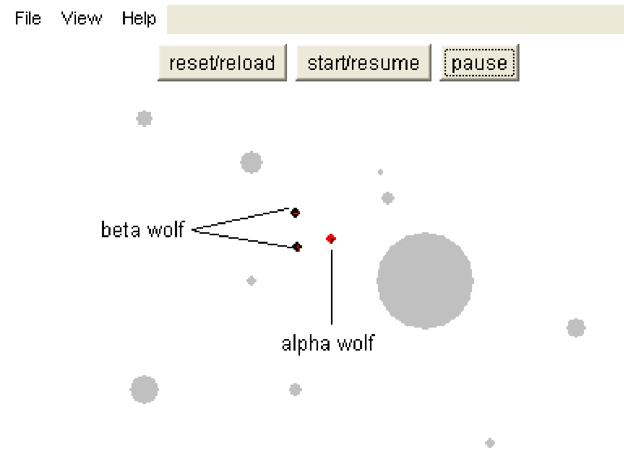

Figure 6. Three wolf “v” formation.

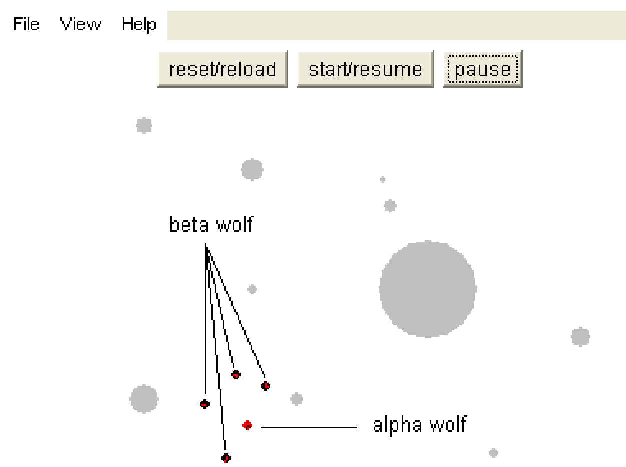

Figure 7. Larger wolf formations.

Table 1 shows the error in the beta wolf formation, indicating how far the wolves are from their expected “correct” position. The data was calculated by obtaining mean values at different positions during the simulation.

Agent	Error position
Beta Wolf 1	0.1 m
Beta Wolf 2	0.3 m
Beta Wolf 3	0.3 m
Beta Wolf 4	0.2 m

Table 1. Mean error distance in the beta wolf formation. No preys are present.

The second scenario is composed of one prey and one predator (alpha wolf). When the simulation begins the alpha wolf starts to persecute the prey, with the prey being significantly faster than the predator. As a result, the alpha wolf never catches the prey, as shown in figure 8.

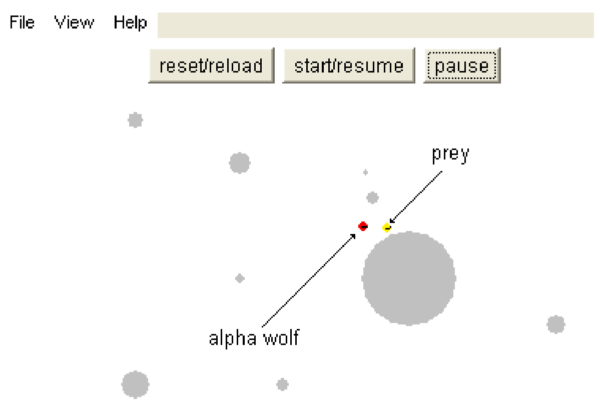

Figure 8. Hunting model with one prey and one predator.

Another variant of this same scene involves four beta wolves in the group, showing that when a wolf sees a prey it does not mean that the rest of the group sees it as well. This results in some members of the group moving in different directions. If the prey is quicker than the predators then the capture process becomes difficult, but it can be resolved by increasing the number of predators in the group.

This increase in predators is necessary only if the speed difference is not too high, since it is not possible to support a group of wolves bigger than four because they begin to crash among themselves or simply disperse. So, if we compare the results obtained in table 2 with the results in table 1 we can see they are very similar, because having one prey only does not modifies much the formation.

Agent	Error position
Beta Wolf 1	0.4 m
Beta Wolf 2	0.2 m
Beta Wolf 3	0.3 m
Beta Wolf 4	0.4 m

Table 2. Mean Error distance on the beta wolf formation. A single prey is present

In the third scene it is more evident the need to modify the hunting behavior of the wolves by introducing some form of communication between them beyond visual contact in order to coordinate movements of the group better, otherwise the group tends to separate when there is more than one prey near. In table 3 we can see the increase in distance errors in wolf formation in the presence of obstacles increased number of preys.

Agent	Error position
Beta Wolf 1	1.5 m
Beta Wolf 2	1.3 m
Beta Wolf 3	1.1 m

Table 3. Mean error distance on the beta wolf formation. More than one prey is present in addition to obstacles.

IV. CONCLUSIONS

The goal of this work was to develop a model inspired in real animals to investigate the concepts of team formation and cooperative agent tasks. The model is limited in several aspects because the wolf behavior can become quite complex. Here, the virtual wolves can only communicate by sight when in real life they do it by sound and smell as well. The fact that the virtual wolf only has sight affects its hunt skills, because the information they can exchange is limited, affecting their hunt behavior in particular when there is more than one prey in sight, usually causing the team to split. When this happen the mechanism to regroup the team is not successful, because it does not consider both alpha and beta wolves as a group.

There are several things that could make this model more realistic such as: use another form of formation to involve more beta wolves, let the agents exchange information that they obtain from the field and make the team attack only one prey to prevent the group from separating, and add to the model motivational variables like fatigue and hunger.

In contrast to results obtained from other multi agent models such as Balch and Arkin [1] that consider both position error and time away from of formation; our model considers only position error and not time away, because almost all the time the agents is not in the formation position. However, in the first two scenes the error position is not too high. But in the third one, this problem is more dramatic. There are many factors affecting these results, such as, unpredictable turns of the alpha wolf, the presence of obstacles, the fact that there is more than one prey in the range of view, the fact that not all the wolves could detect the prey at the same time as opposed to real wolves, etc.

One of the more important aspects of the model is that it shows how cooperation emerges in the team. When there is one predator in the environment it is not possible to capture the prey, but when there is more than one predator it becomes an easier task. After several simulations we found that the wolf team captures the prey faster if the number of team members increases, but there is a limit after which the members star to limit the mobility of their partners. We found the maximum number of wolves in our experiments before this happened to be five beta wolves and one alpha wolf.

Finally, the model has various limitations and could be extended in many ways such as making the formation on the wolf team change dependant of the position of the prey, adding others forms of communications between the wolves that permit information exchange with the environment and adding emotional variables to the predators as well as the prey.

V. REFERENCES

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