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Finding the minimum value of a function using the emergence phenomenon of boids

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Abstract—Living organisms often behave as if they have a will as a group by individually receiving influences from their surroundings and acting in accordance with those influences. Research on artificial life aims to reproduce this behavior on a computer and to create new information processing technologies from it. In this paper, we focus on Boids, one of the most famous artificial life models. The roles of "predator" and "prey" for each agent in Boids, and the phenomena that emerge in a system that also incorporates the annihilation and division functions of the agents themselves, are discussed.

1. Introduction

Since Christopher Langton coined the term Artificial Life (ALife) in the late 1980's[1], there have been various studies on artificial life. While the current research in artificial intelligence, as represented by deep learning, aims to optimize objectives, artificial life is a research field that examines life-related phenomena and systems by simulating life.

One of the systems to simulate such artificial life is Boids[3]. In Boids, multiple agents can move around in computer space, and various phenomena are emergented by their behaviors while influencing each other. How each agent influences the movements of the other agents is controlled by parameters of each agent. In Boids proposed by Reynolds[3], the velocity vector for each Boid's own movement is determined by "Separation", "Alignment", and "Cohesion".

"Separation" generates a velocity vector to control the movement of one agent to avoid another agent if it gets too close. "Alignment" generates a velocity vector to control the movement of an agent so that it moves in accordance with the direction of the entire herd and its movement speed. "Cohesion" generates a velocity vector that controls the movement of an agent toward the center of the herd. In other words, "Cohesion" works to bring the agents closer together to form a swarm, and Alignment controls the movement of the entire swarm. "Separation" is used to reduce the density of an overcrowded herd. Depending on the strength of these three parameters, a variety of phenomena can emerge in the entire herd.

In this study, we give the roles of predator and prey to the agents of the Boids system. In other words, the purpose of this study is to experimentally confirm how predators and prey, when present in the Boids system, will swarm in response to predator movement. We then observe what phenomena emerge depending on the parameters.

2. Operating range of Boids fundamental parameters

The fundamental behavior of each agent in Boids is determined by "Separation", "Alignment", and "Cohesion". These parameters are determined by the specific amount of control depending on the positional relationship with other agents. First, we consider the parameters by which each agent measures its relationship with other agents. "Separation", "Alignment", and "Cohesion" are determined by "Distance", a parameter of the distance between itself and other agents, and "Angle", a parameter of the range of attention to recognize other agents with respect to its own direction of movement, as shown in Fig. 1. "Angle" is determined by "Separation", "Alignment", and "Cohesion" shall be affected when there are other agents within an angle range of −Angle to +Angle and their distance is less than or equal to "Distance", with respect to the direction in which they are moving. In other words, the "Distance" and "Angle" are used to set the range within which other agents

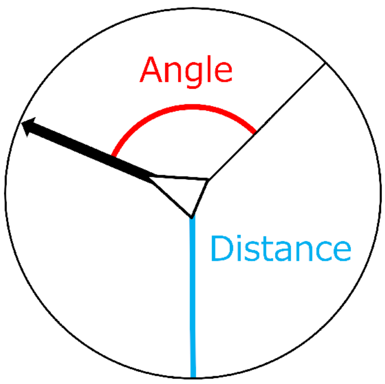

Figure 1: "Distance" and "Angle"

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are recognized. The range can be set to different values depending on “Separation”, “Alignment”, and “Cohesion”. This makes it possible to generate changes such as making it easier to form swarm.

3. Velocity update

The position of each agent is updated by the movement vectors derived by “Separation”, “Alignment”, and “Cohesion”. Let $\boldsymbol{x}_i$ be the position vector of the i-th agent and $\boldsymbol{v}_i$ be its velocity vector. We define T_S, T_A, and T_C as the regions of influence of “Separation”, “Alignment”, and “Cohesion” determined by ”Angele” and ”Distance”, respectively.

The position vector $\boldsymbol{x}_i$ and the velocity vector $\boldsymbol{v}_i$ are updated by Eq. (1).

$$\begin{cases} \boldsymbol{v}_i & \leftarrow \boldsymbol{v}_i + F_S \sum_{j \in T_S} \left(\boldsymbol{x}_i - \boldsymbol{x}_j \right) + F_A \left(\frac{1}{N_{T_A}} \sum_{j \in T_A} \boldsymbol{v}_j - \boldsymbol{v}_i \right) \\ & \quad + F_C \left(\frac{1}{N_{T_C}} \sum_{j \in T_C} \boldsymbol{x}_j - \boldsymbol{x}_i \right) \\ \boldsymbol{v}_i & \leftarrow \begin{cases} \boldsymbol{v}_i & \text{for } |\boldsymbol{v}_i| < \boldsymbol{v}_c \\ \mathrm{Sign}(\boldsymbol{v}_i) \cdot \boldsymbol{v}_c & \text{otherwise} \end{cases} \\ \boldsymbol{x}_i & \leftarrow \boldsymbol{x}_i + \boldsymbol{v}_i \end{cases} \tag{1}$$

where $\boldsymbol{v}_c$ is a preset criterion velocity vector, N_{T_A} and N_{T_C} denote the number of agents in the regions T_A and T_C, and F_S, F_A and F_C are parameters.

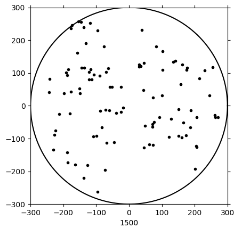
We observe the behavior of the agent when the parameters F_S, F_A, and F_C are varied in Eq. (1).

4. Flocking with Boids

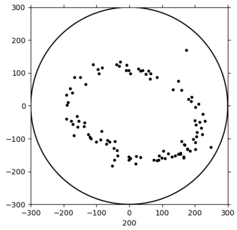
Three types of flock Dynamic parallel group, torus, and swarm with Boids are shown in Fig. 2. In Dynamic Parallel Group, the flock itself extends throughout the simulation space, and the agents move freely. In Torus, the individuals gather to form a line and rotate in a circle-like swarm. Swarms are solid groups, but the group itself does not move much, and each individual moves in various directions within the group. The parameters of each swarm are shown in Table 1, Table 2 and Table 3. Dynamic parallel group when Cohesion Distance and Alignment Distance are small and Cohesion Distance is smaller than Alignment Distance. When the Force is small and the Distance is large, it becomes a torus. When the Distance and Angle of Cohesion are large, it becomes a swarm.

Table 1: Dynamic parallel group parameters

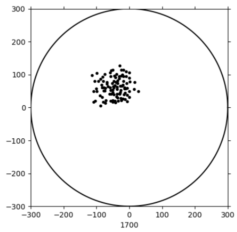
	FORCE	DISTANCE	ANGLE
Separation	0.500	5	90
Alignment	0.050	30	90
Cohesion	0.008	20	90



Dynamic parallel group



Torus



Swarm

Figure 2: Boids

Table 2: Torus parameters

	FORCE	DISTANCE	ANGLE
Separation	0.500	5	90
Alignment	0.010	50	90
Cohesion	0.005	80	90

5. Predation

Predation is determined when the predator and prey agents approach each other. When the distance between the predator and the prey is less than a certain distance, the prey is removed from the virtual space as if the prey was preyed upon by the predator.

Predator and prey move in the relationship is shown in Fig 3. The prey moves with Separation, Alignment, and Cohesion from the prey, and the prey is also subject to Separation from the predator. The predator has only Cohesion to the prey.

Table 3: Swarm parameters

	FORCE	DISTANCE	ANGLE
Separation	0.500	5	90
Alignment	0.010	50	90
Cohesion	0.002	80	180

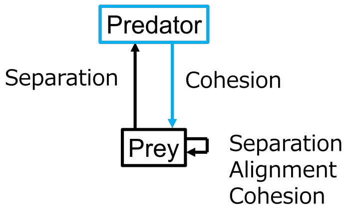


Figure 3: Predation

6. Experiments

Adding predators to a group of Boids. Two predator patterns are used in this experiment. The parameter Cohesion1 for predator 1 and Cohesion2 for predator 2 are shown in Table 4, and the Separation of the prey to the predator is shown in Table 5. The Distance and Angle of this Separation are set to the same maximum values as the other Distance and Angle values used so far. This is because we assume that these values are the limit of the agent's function. The predator's Distance is set to the same value as that of the prey, because the purpose of this experiment is not to prey on the prey but to change the movement of the herd.

Table 4: Predator Cohesion Parameters

	FORCE	DISTANCE	ANGLE
Cohesion1	1.000	80	60
Cohesion2	1.000	80	120

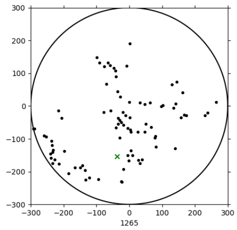
When predator 1 is added, the Boids flock move to avoid the predator while retaining the characteristics of each flocks movement, as shown in Fig 4. In the dynamic parallel group, the change in the movement of the flock is small because the agents are free to move before the predator is added. In the swarm, however, the predator avoidance movement cause the flock to collapse, resulting in a large change in movement.

Predator 2, like the addition of predator 1, avoid the predator while retaining the movement characteristics of each herd. Figure 4. The change in the predator parameter Angle from 60 to 120 make the predators more sensitive to the surrounding prey. Instead, the number of predation decrease because predators are less likely to chase a single agent.

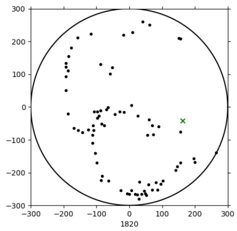
The results of 10 simulations of each of the three types of herd movements dynamic parallel group, torus, and swarm are plotted. The vertical axis is the average distance from the center of the simulation space to each agent. The horizontal axis is the variance of the distance, distributed over the time from 1000 to 2000 epochs.

Table 5: Prey Separation parameters for predators

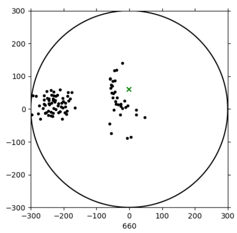
	FORCE	DISTANCE	ANGLE
Separation	1.000	80	180



Dynamic parallel group



Torus



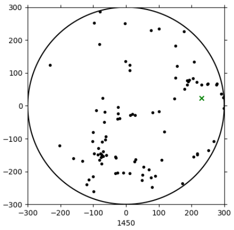
Swarm

Figure 4: Boids with predator1

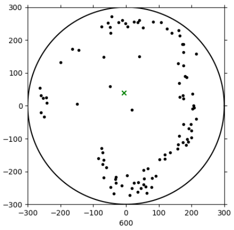
In Fig 6, before adding the predator, the Boids plots are divided by flock movement. In Fig 7 and 8, where predators have been added, the plots are mixed, making it difficult to classify the three types of movements.

7. Conclusions

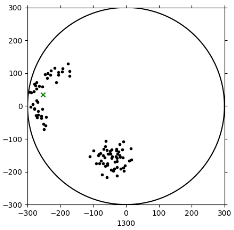
We confirmed that various flock movements emerged depending on the parameters. When a predator is added, the characteristics of the flock movement before the addition of the predator remain, but the evaluation values change so much that it is no longer possible to discriminate the flock pattern by the distance of the agent from the center. The increase in the value of the variance suggests that the prey



Dynamic parallel group



Torus



Swarm

Figure 5: Boids with predator2

became more active after the predators are added.

Acknowledgments

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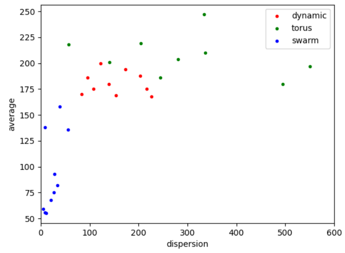

Figure 6: no predator

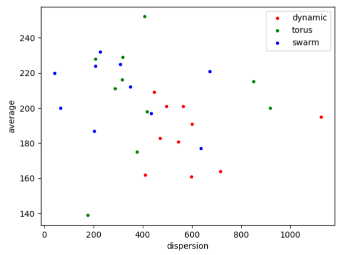

Figure 7: predator1

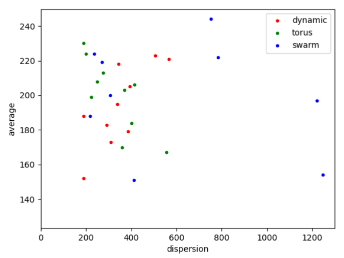

Figure 8: predator2