Introduction:

Ecological studies have long established that cooperative behaviors adopted by groups of organisms have certain survival advantages in their inhibited environments. From wolf packs to fish schooling, group-level, cooperative strategies emerge from individual organisms as each of them follow seemingly simple protocols. However, is there ever a time in which cooperation fails? Or when cooperation would not be the most optimal strategy to adopt? In this study, we examine cooperation in terms of packing, in which organisms join together to form and operate in larger and larger groups. We propose that, initially, more cooperative preys have an advantage in increasing population due to feasibility in finding food sources by relying on their fellow members. They also become more prone to predation as they are more readily exposed to predators as soon as their fellow members are attacked, leading to sharper decreases in population.

Background:

Drawing inspiration from the classic predator-prey model and the boids model[3], our predator-prey cooperation model encapsulates the fundamental principles of separation, alignment, and cohesion observed in flocking behavior. This model aims to emulate behaviors seen in real-world scenarios, such as the cooperative dynamics of wolves and fish. Wolves, known for their pack behavior, rely on cooperation for survival, hunting, and raising offspring[1]. Similarly, fish schooling exhibits coordinated movements within a group, offering advantages like predator protection, increased foraging efficiency, and effective navigation[2]. The synchronized movements of a fish school can even deter and confuse predators. Informed by these natural behaviors, our exploration involves examining diverse cooperation levels to identify optimal conditions for predator survival.

Method:

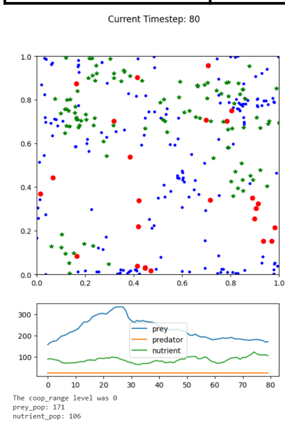
The model incorporates three types of agents: preys, predators, and nutrition. The main agent we are observing is prey, as their survival is affected by the amount of food they receive as well as the predators around them. Movement, speed, and direction, in this model, occurs by adjusting the velocity of the moveable agents. Two variables account for velocities, dx, for movement in x-axis, and dy, for movement in the y-axis. Factors influencing direction and speed of movement(running from predator, running to food, etc) affect these two variables. They are then appended to the current location of the agents, hence updating the location of agents in each timestep. The interactions and behaviors of these agents are modeled in a two-dimensional space. The simulation takes place in a wrapped space with no borders, allowing agents to move freely and around edges. Each simulation was run for 80 timesteps to study how the populations varied over time. The number of living prey, predators, and nutrients were tracked at each timestep.

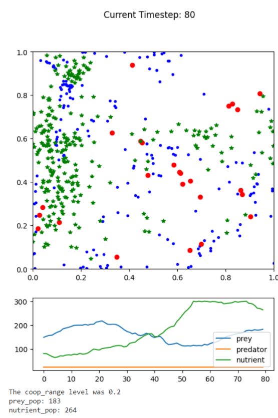
To mimic simplistic behavior, prey undergoes simple decision-making: escape, obtain food, or flock. It first detects whether any predators are close by within the prey's visual range, triggering an escape behavior if so. If not, the prey then checks for any nearby nutrient sources to move towards. If not, the prey then undergoes clustering with other nearby prey agents. Three specific characteristics are accounted for within clustering behavior: coherence(moving towards the cluster's center), separation(avoiding collision by ensuring a minimal distance from nearby agents), and alignment(matching speed and direction with nearby agents). These factors modify the velocity of the agent which then later appended to their location. After moving, the prey's energy is decreased. If prey runs out of energy, they would die. As such, it is essential for them to find nutrient agents. By consuming a nutrient agent, the prey receives energy to persist. Moreover, by reaching a certain energy threshold, prey can reproduce with certain probability. The level of cooperative clustering in our model is defined by the range of nearby prey that the prey can perceive. Essentially, how many preys that are taken into account when a prey undergoes clustering movement. If the level is set low, that means a prey will only consider a few nearby preys when undergoing clustering, if the level is set high, preys will perceive a larger range of prey around them, taking into account all their location and velocities. The visual range for perceiving nutrients and predators remain the same throughout. Initial attempts at modifying clustering level were taken by modifying the coherence and alignment parameters when modifying clustering behavior by the preys. However, we later discovered that manipulating such variables did not yield significant shifts in clustering effect. Much more prominent effect occurs when the level of clustering is defined by the range of preys that each prey is clustering with.

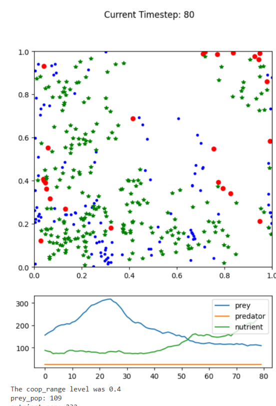
Predators move directly toward any prey agents detected within their visual range. But they do not need food or energy to persist. If no prey is nearby, predator agents wander randomly. They only interact with prey agents as they do not predate upon nutrients. The nutrient agents are stationary that spawn randomly throughout the environment up to a maximum carrying capacity. Additional nutrient agents are more likely to auto-generate near existing ones if the nutrient population is below the carrying capacity. As such, later in the model, nutrient agents appear in patches to simulate concentrated areas of food resources.

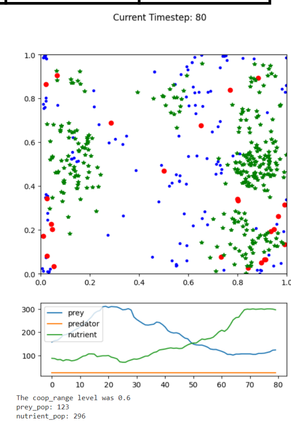
Results:

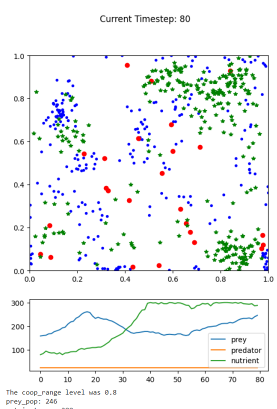
Cooperativity level	0	0.2	0.4	0.6	0.8	1	1.2
Average survival of prey (from 5 trials)	167.4	165.8	117	118	223	225.4	134.6

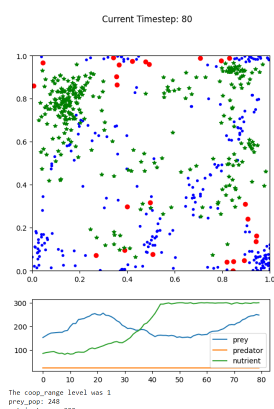












Conclusion:

In our investigation, we systematically varied the cooperativity level between 0 and 1 in 0.2 increments, analyzing its impact on prey survival in our dynamic model. For cooperativity levels of 0 and 0.2, the average prey survival remained similar, hovering around 166 individuals. As cooperativity increased to 0.4 and 0.6, we observed a decline in average survival to approximately 117 preys. Remarkably, when the cooperativity level reached 0.8 and 1, there was a substantial improvement in prey survival, showcasing the effectiveness of higher cooperativity. However, at a cooperativity level of 1.2, we witnessed a decrease in survival, indicating a potential saturation point where cooperation or clustering becomes less effective.

The data suggest that a cooperativity level between 0.8 and 1 facilitates the highest prey survival, attributed to enhanced abilities in finding food and evading predators. The increased cooperativity enables prey to outpace predators more effectively, as the crowded environment obstructs direct predator paths. Moreover, the collective presence of prey provides protection during feeding. Surprisingly, even at lower cooperativity levels (0 and 0.2), significant survival was observed, possibly due to inherent clustering in confined spaces and individualistic foraging behaviors. Conversely, a cooperativity level around 0.5 proved challenging for predators, as they lacked the benefits of group protection for resources and predator evasion. In summary, our findings underscore the optimal effectiveness of cooperation in the range of 0.8 to 1, facilitating superior prey survival through effective clustering strategies.

Certain observations can be made from examining our model when running. First of all, clustering of three or more preys occurs even if the clustering level is set to low or zero. This possibly indicates that, by virtue of following simplistic rules of evading predators and going towards food, clustering behavior would naturally arise whether intentionally implemented or not. A possible explanation for this phenomenon is that prey of nearby locations are subjected to similar environmental influences and the same behavioral rules, hence they would behave similarly. As such, they would move in similar directions and velocities, appearing as if they are clustering. Moreover, by examining models under different clustering levels, it seems that no extremely large clusters ever form. There is little size variation of the largest, observable, cluster in the model under different clustering conditions. This could suggest that the decision-making process implemented in preys(first evade predators, then go for food, then cluster) cap the maximum size of the clusters able to form. Because individual survival is ranked higher in prey decision-making, any large cluster of prey cannot maintain their constant formation since the outer layer of prey is constantly being attracted towards nutrition and repelled by predators.

Since our model solely concentrates on how clustering behavior affects prey survival, we made it so that the predators cannot die since their sole function in our model is to predate on prey. This is not a setup that is realistic to the real world as predator and prey populations should have a two-way effect on each other. To extend on this limitation, we can make predator survival depend on consumption of prey as well. Moreover, we can extend clustering behavior to predators as well to determine how clustering behavior can benefit predators in catching prey. A food chain of different species preying on each other can be set up with each species also following a certain clustering process. Another major limitation is that our model can only simulate clustering behavior exhibited in organisms with lower intelligence. The decision-making process implemented in preys is rather simplistic. It may palely imitate behavior of fish in fish-schooling but in regards to clustering behavior of more intelligent organisms, for instance, wolves in packs, it does not simulate it well. To extend upon this, we can build a more sophisticated decision schema for preys such that when they move into clusters, they will be automatically assigned roles, some for navigation(controlling the direction of movement for the whole cluster), some for fending/distracting predators, etc. They will no longer look out for their individual survival like in the current model, instead they will take on a functionality responsible for the survival of the group.

Literature:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4006263/ [1]

https://royalsocietypublishing.org/doi/10.1098/rsfs.2012.0033 [2]

https://github.com/beneater/boids [3]

https://www.netlogoweb.org/launch#https://www.netlogoweb.org/assets/modelslib/Curricular%20Models/BEAGLE%20Evolution/EACH/Cooperation.nlogo