CS 361 - Artificial Life and Digital Evolution
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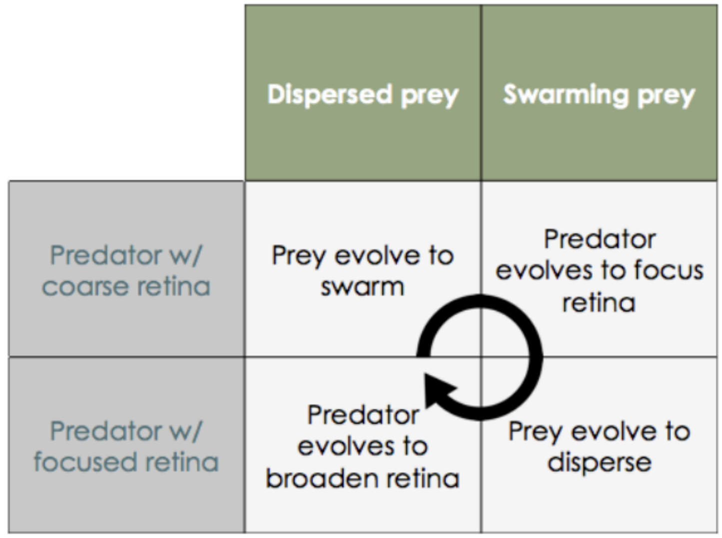
Replication Report

Summary of the methodology of the original paper:

The original paper investigated the fitness of organisms through predator vision, prey dispersion, and the predator confusion mechanism to assert the claim: "Eyes in the front, the animal hunts. Eyes on the side, the animal hides." To examine this evolutionary phenomenon, the researchers employed an agent-based computational model using a toroidal grid environment where predators and prey interact and coevolve over successive generations. They implemented neural networks (Markov Networks) to control agent behavior, allowing these machines to make decisions based on sensory inputs and internal memory states. The predator confusion effect was integrated as a perceptual constraint on the predator's visual system, while a genetic algorithm drove evolutionary change by selecting more effective hunting and survival behaviors.

Summary of the results from the original paper that you attempted to replicate

The original study successfully demonstrated a clear coevolutionary cycle between predator visual systems and prey swarming behavior through quantitative analysis of 30 replicate experiments, with the predator's visual system serving as the primary driver of this cycle. When predators had narrow visual systems (≤60° frontal coverage), swarming became ineffective as an anti-predator strategy and prey evolved to disperse. However, when predator visual coverage expanded to 120° and beyond, prey swarming re-emerged as a viable defense mechanism, achieving significantly higher swarm densities of 6.13 ± 0.76 at the same generation. Researchers found a significant negative correlation between predator view angle and prey swarm density across all experiments ($P \leq 0.001$), confirming that as predator vision narrowed below 100°, prey evolved to disperse rather than swarm. According to the paper, this cyclical dynamic occurs because broader vision provides foraging advantages against dispersed prey, creating conflicting demands for both prey discovery (broad vision) and prey tracking through swarms (narrow, high-acuity vision) that drive the evolution of complex visual systems in predators.



Description of your reimplementation and any changes you needed to make from the original approach:

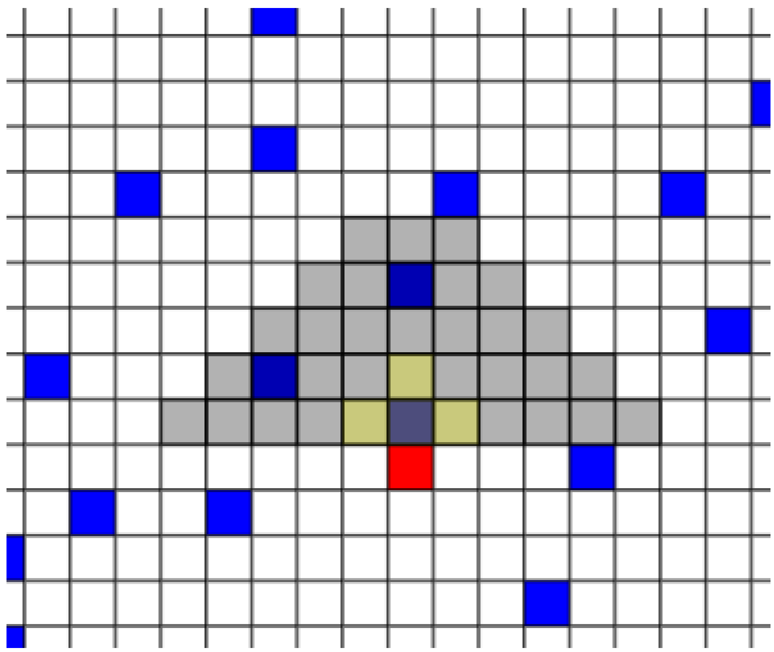
Description:

Our reimplementation creates a simplified agent-based model using a 40x40 toroidal grid populated with a single predator and 100 prey organisms. The predator possesses a configurable vision system defined by height and width parameters that create a pyramid-shaped visual field extending northward from its position. This visual architecture allows the predator to detect prey within its field of view and pursue the closest visible target using Manhattan distance calculations. The predator's attack capability is constrained to a fixed 3x2 grid directly in front of it, standardized across all predator agents regardless of their vision parameters.

Several key mechanisms from the original paper have been successfully implemented in our system. The predator confusion effect operates through the formula $P_{capture} = 1/A_{NV}$ where ANV represents the number of prey agents visible to the predator, directly reducing attack success as prey density increases within the visual field. Handling time constraints limits predators to one attack attempt every 10 simulation time steps, simulating the biological reality of prey processing and refocusing delays. Prey behavior is governed by distance-based movement functions that enable both swarming and dispersal strategies: MoveTowardPrey() maximizes adjacent prey neighbors for swarming behavior, while MoveAwayFromPrey() minimizes nearby prey for dispersal behavior.

How does it differ:

Our implementation is drastically more simplified than the original approach. Rather than employing Markov Networks for decision-making, we use deterministic algorithms for movement and vision calculations. Predator vision is fixed in a northward direction without the ability to rotate or scan different orientations, and prey behavior is directly controlled by boolean flags (prey_swarm_mode) rather than evolved neural networks. The fitness calculation is simplified to immediate prey consumption counts for predators and survival-based scoring for prey, without the complex genetic algorithm optimization used in the original study. While this simplified approach lacks the evolutionary dynamics of the original paper, it provides a clear foundation for testing the core predator confusion mechanism and its effects on predator-prey interactions.



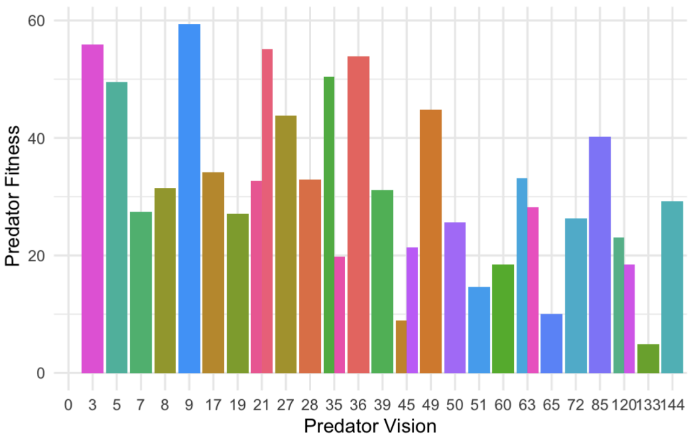
(Picture from GUI:)

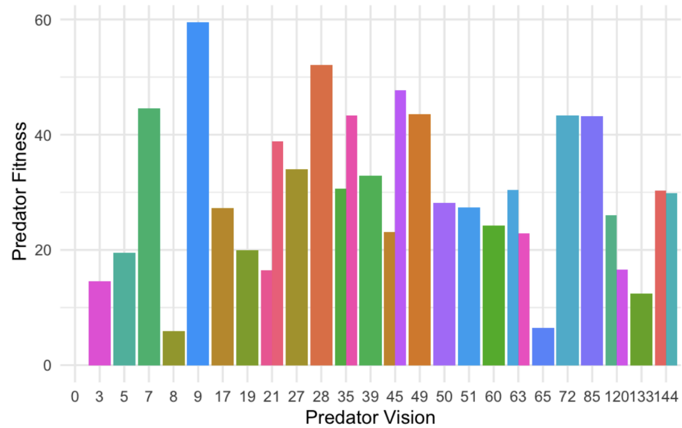
(<u>Blue</u>: Prey | <u>Red</u>: Predator | <u>Yellow</u>: Predator Attack Range | <u>Shaded</u>: Predator Vision)

Description of your replication results:

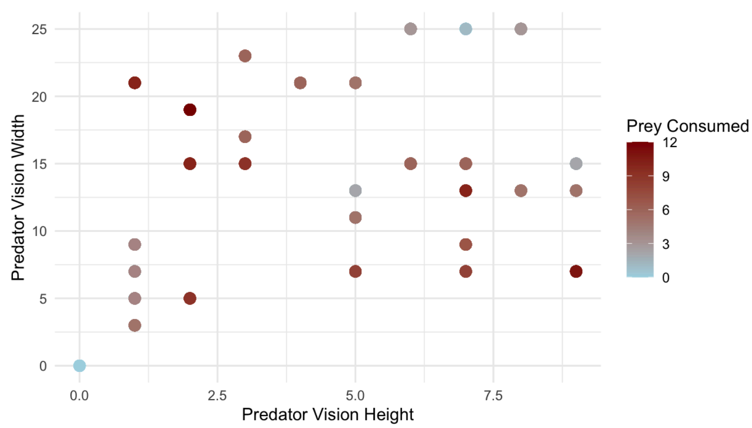
Despite the simplicity of our implementation, we have managed to show the key behaviors and interactions associated with vision range and prey behavior.

Our definition of fitness is similar to that in the paper. It is the sum of each n simulation steps over the number of prey that have been consumed.





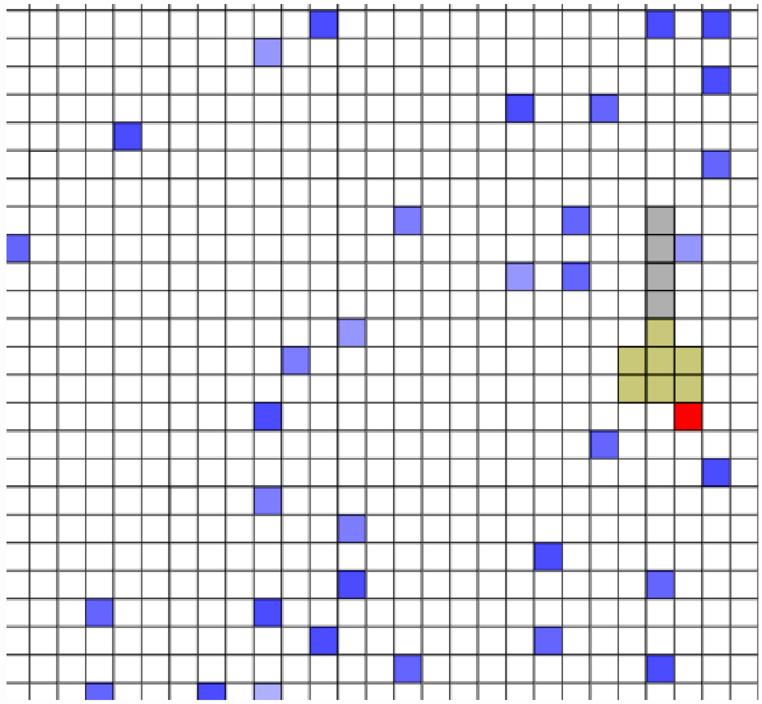
To the right is Dispersive prey simulation and to the left is swarming prey simulation. The following two graphs show the relationship between predator vision and fitness. Predator vision is equal to the number of blocks in which the predator can see prey. We see that during simulations with dispersive prey, predators with less visual range tend to be more successful because of the predator confusion mechanism. In comparison, during simulations with swarming prey, predators tend to be more fit when their visual range falls within median values.



This graph shows the amount of prey consumed on dispersive prey relative to the width and height of predator vision. Some predators may have vision that is more broad than narrow and vice versa. We see that predators consume more prey when they have a large width to their visual range, which supports the hypothesis that a broad visual range is advantageous when competing against dispersive prey. We also see that when the visual range is too large, it contains a large height and width, the predator becomes less fit due to the predator confusion mechanism

Our graphs may not look exactly like those from the paper implementation, although they show the big picture idea that we aimed to replicate. Our predator confusion mechanism successfully alters the fitness of predators based on their visual range, while showing successful visual ranges.

Expansion (Camouflage)



(Picture from GU w/ Camo:)

(Darker prey = less camo values, Lighter prey = higher camo values)

The camouflage system adds a hide-and-seek dynamic between predators and prey in the predator-prey simulation. When predators scan their vision area, prey now have a chance to avoid detection entirely.

How It Works -

Detection Phase

1. **Predator Vision:** When a predator looks around, it identifies all prey within its field of vision
2. **Camouflage Roll:** Each visible prey makes a "camouflage check" - a probability roll based on their current camouflage ability
3. **Success vs Failure:**
    - **Successful hide:** The prey remains undetected and cannot be attacked this turn
    - **Failed hide:** The prey is spotted and becomes a valid target for attack

Learning Mechanism

- **Improvement**: Each time a prey successfully hides, its camouflage ability gets slightly better (increases by the `camouflage_value` parameter, set to 0.1)
- **Experience**: The more often a prey escapes detection, the better it becomes at hiding in future encounters

Visual Feedback

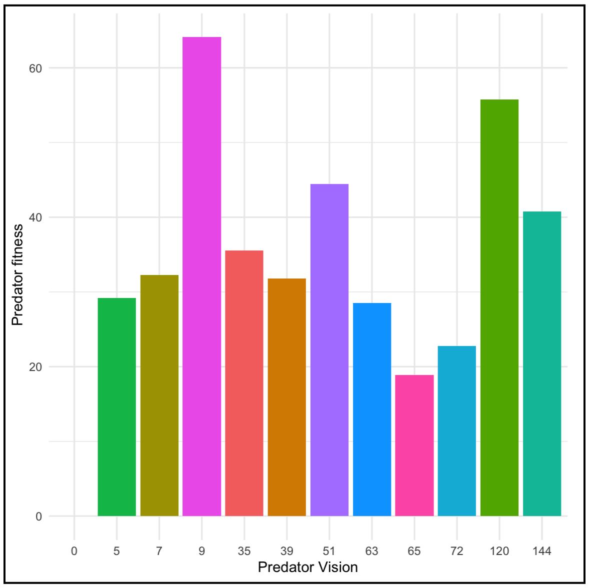
- **Transparency Effect**: As prey become better at camouflaging, they appear more transparent in the GUI
- **Real-time Indication**: Viewers can visually see which prey have developed stronger camouflage abilities by stepping through the simulation

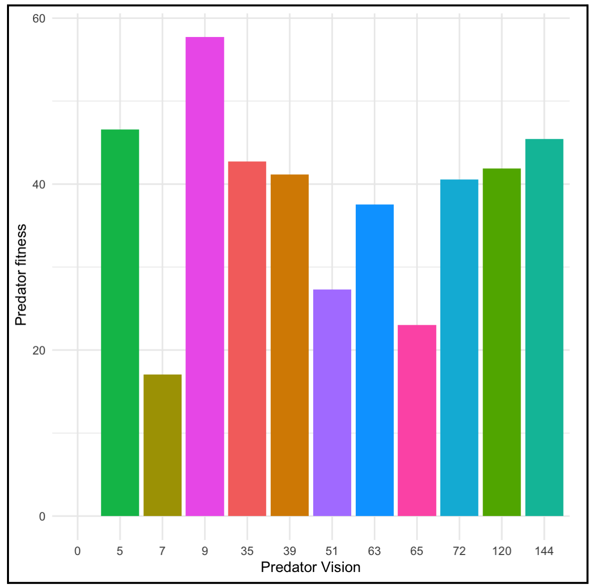
Technical Implementation

- Each prey starts with a base camouflage probability
- The system uses `random.GetDouble() < prey_camouflage_value` to determine hiding success
- Only prey that fail their camouflage check are added to the "spotted prey" list for potential attacks
- Camouflage values accumulate over time, making experienced prey increasingly elusive

This expansion adds evolutionary pressure for prey to develop better hiding abilities while maintaining the predator-prey balance through learned behavior.

Expansion Data:





The following graphs above show predator fitness by vision with the inclusion of camouflage. The data on the right is simulated with dispersive prey, and on the left we have swarming prey. Although this data was run on fewer trials than the previous graphs, we see that predator fitness has dropped and leveled out among the differing visual ranges. Allowing prey to camouflage reduces the fitness of predators.