Wildlife simulation with boids

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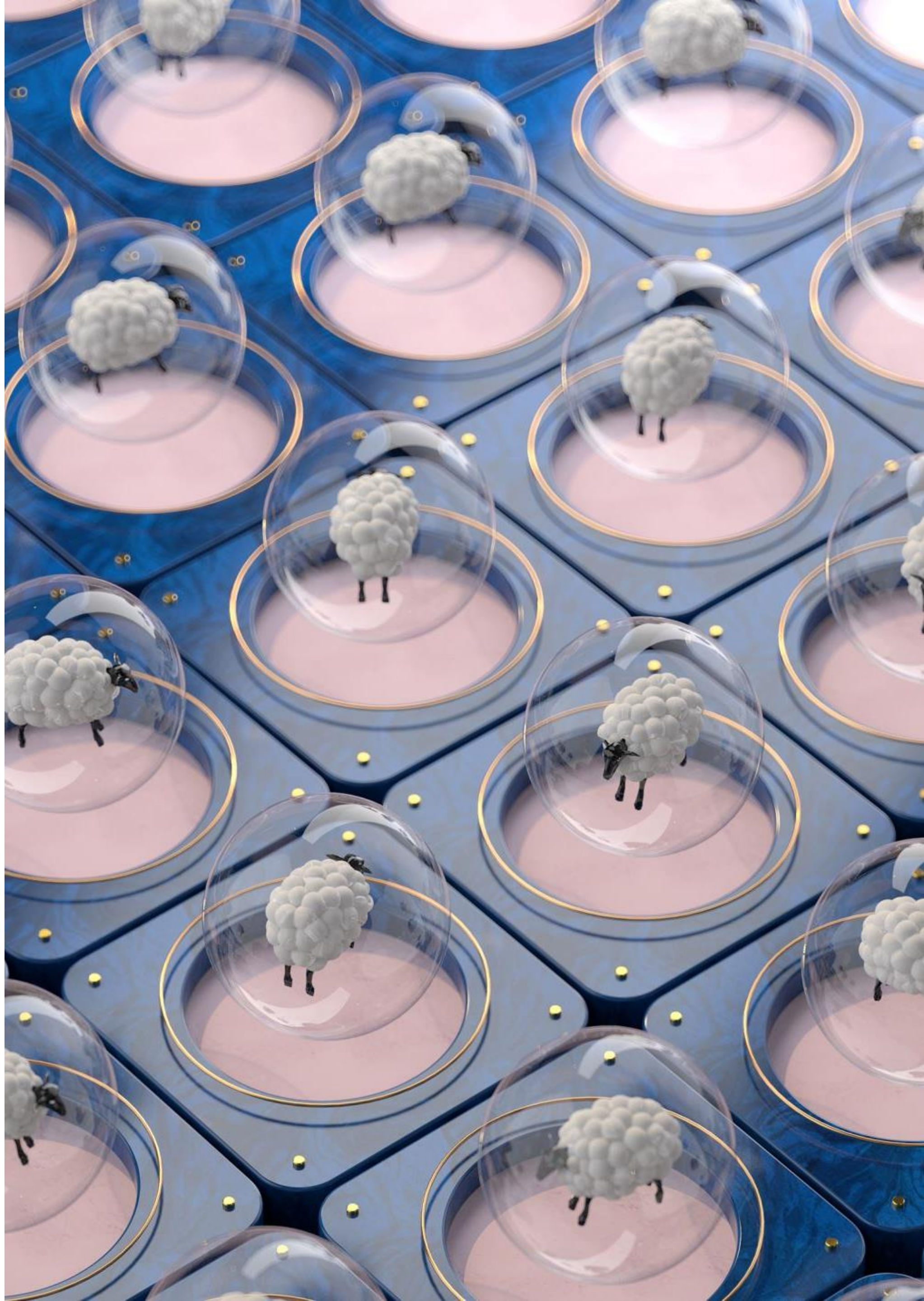
GOAL OF THE PROJECT

Develop and evaluate an AI-driven wildlife simulator that models prey–predator interactions where agents forage based on local rules, exploit refuges and multiple food sources, and navigate environments with dependable obstacle avoidance.



MOTIVATION

Thanks to this project and the data collected through our experiments, we will be able to study how natural systems behave under different simulated factors and conditions.

This analysis will help us understand the mechanisms that give rise to complex collective behaviors and apply this knowledge to the field of Artificial Intelligence.

USEFUL METHODS AND ALGORITHMS

Efficiently locate food sources using simple local rules

Schloesser, D. S., Hollenbeck, D., & Kello, C. T. (2021)
"Individual and collective foraging in autonomous search agents with human intervention"

The study analyzes how simple local rules can produce efficient individual and collective foraging behavior without complex learning or communication.

Behavioral rules:

- Move towards food when detected.
- If no food detected, explore using standard movement rules.
- Other agents can detect agents that have located food and converge toward them (social attraction / chaining effect).

- Hunger-driven behavior: Agents move toward food only when a given condition (e.g., energy < hunger_threshold).
- Detection radius: Each agent senses food within a predefined radius.
- Social attraction to food: Other agents converge to the same food if they see a hungry agent that has located it.
- Movement: Combine boid rules with food attraction vector.

Prey refuges and additional food sources

Chakraborty, K., Kar, T. K., & Jana, S. (2017)
"Interactive effects of prey refuge and additional food for predator in a diffusive predator-prey system"

The paper studies how environmental factors can stabilize or destabilize predator–prey ecosystems by including two realistic mechanisms:

Prey refuge (m): a proportion of prey can hide in protected areas.

Additional food (β): predators can access other food sources besides prey.

- Pray refuge(m): Safe zones in the environment (green circles) where predators cannot see or reach prey.
- Additional food (β): “Food spots” that predators can visit to recover energy instead of hunting prey.
- Predators consume energy each frame and regain it either by hunting or visiting food spots.

Simulation with obstacles and avoidance behaviour

Nguyen, Q. C. (2024).
"Monte Carlo Analysis of Boid Simulations with Obstacles: A Physics-Based Perspective."

It explores how individual agents can detect and avoid static obstacles while maintaining natural group movement.

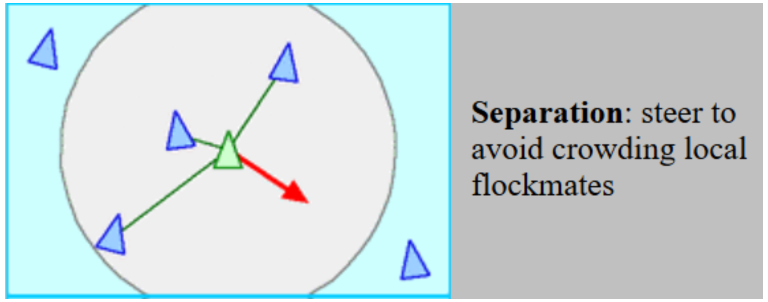
It adds new steering behaviors based on repulsion vectors and Monte Carlo analysis to evaluate different avoidance strategies.

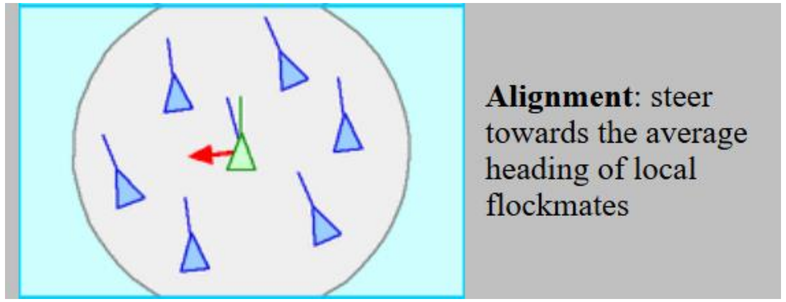
- Obstacle detection: each agent scans its surroundings within a fixed obstacle radius to identify nearby barriers.
- Avoidance behavior:
  - When an obstacle is detected, a repulsion vector is generated opposite to the obstacle's direction.
  - The agent's total velocity combines standard Boid rules (separation, alignment, cohesion) with this avoidance vector.
- Smooth redirection: instead of abrupt turns, agents gradually adjust orientation to maintain realistic flocking motion.

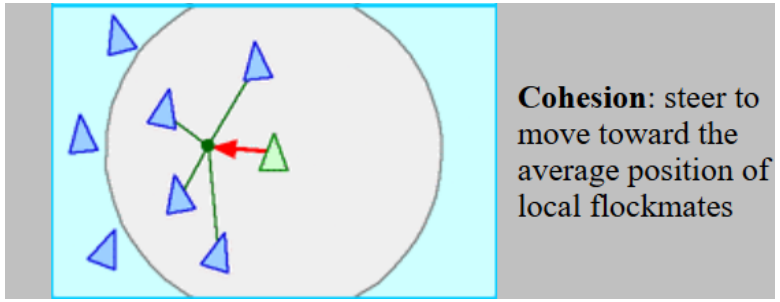
Implementing Flocking Behavior of Prey

Craig W. Reynolds. (1987)
"Flocks, Herds, and Schools: A Distributed Behavioral Model"

- This paper introduces how simple, decentralized rules assigned to each agent can generate a lifelike flocking pattern.





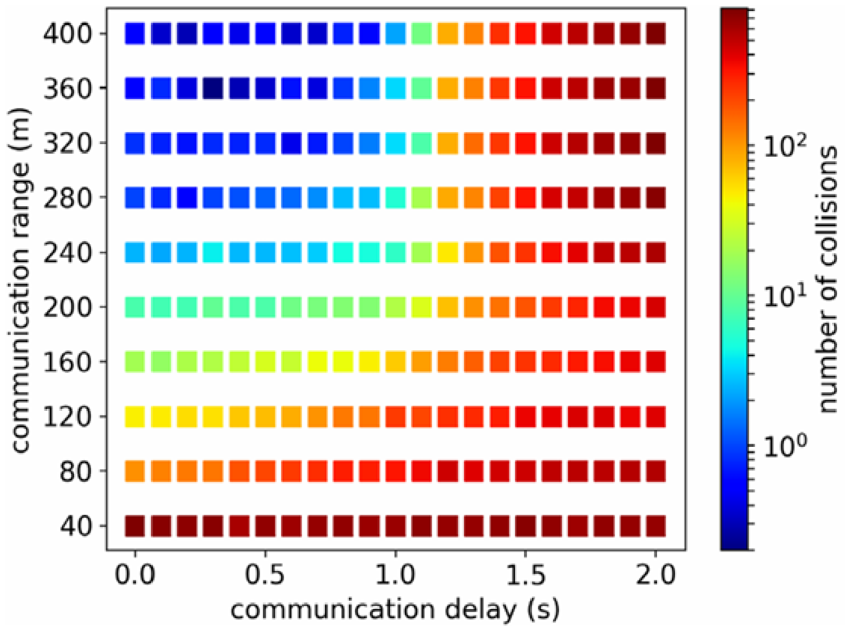


Realistic scenario

Iztok Lebar Bajec, Miha Mraz, Nikolaj Zimic. (2005)
"Simulating Flocks on the Wing: The Fuzzy Approach"

Vásárhelyi, Gábor; Virágh, Csaba; Somorjai, Gergő; Nepusz, Tamás; Eiben, Agoston E.; Vicsek, Tamás (2018)
"Optimized flocking of autonomous drones in confined environments "

- Both papers argue that classical boids assumes access to crisp, numerically precise information and exact calculations that real animals are unlikely to have. This reduces perceptual realism and also hurts performance.



Overreactions and instability

Alignment is the most impactful steering

I. Lebar Bajec (2002)
"Computer model of bird flocking"

- Simulation showed that alignment -velocity matching- is the steering function with highest influence on the boid's ability to flock.
- Good velocity matching with its nearby flockmates, makes unlikely that collisions with any of them any time soon.

Description of steering force
1. Collision Avoidance: avoid collision with nearby flockmates.
2. Velocity Matching: attempt to match velocity with nearby flockmates.
3. Flock Centring: attempt to stay close to nearby flockmates.

Table 1: Reynold's steering forces.

Iztok Lebar Bajec, Miha Mraz, Nikolaj Zimic. (2003)
“Boids with a fuzzy way of thinking”

Fuzzy logic approach

- The paper explores how implementing the Boids' alignment rule with fuzzy logic instead of precise math can achieve similarly realistic and stable flocking behavior as the classic approach.

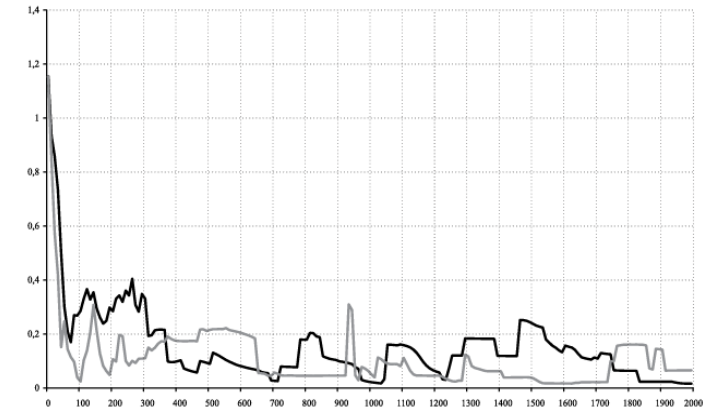


Fig. 6: Average heading variation for the crisp (black) and fuzzy (gray) implementations of the alignment steering function.

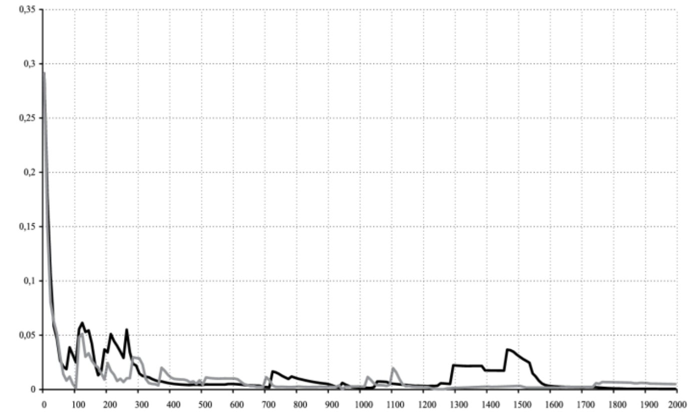


Fig. 7: Average speed variation for the crisp (black) and fuzzy (gray) implementations of the alignment steering function.

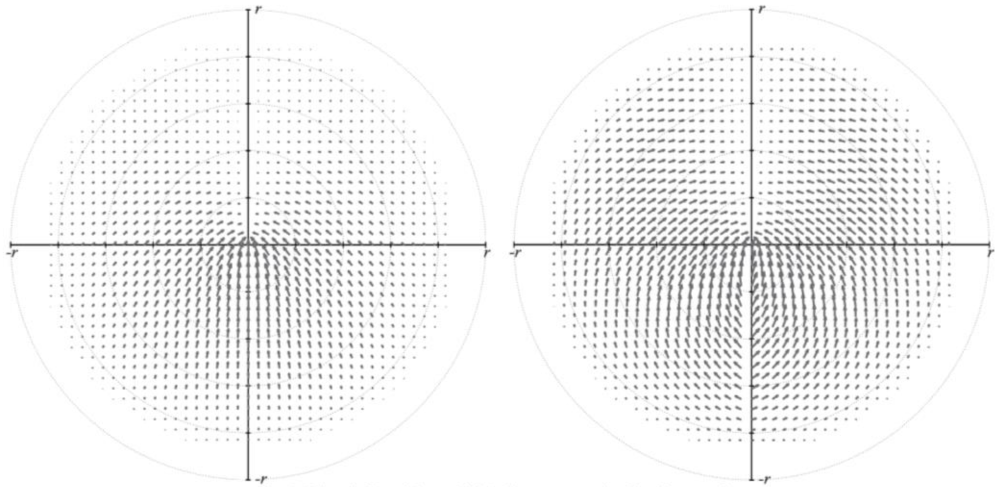


Fig. 4: Crisp (left) and fuzzy (right) alignment steering functions graphs.

Iztok Lebar Bajec, Miha Mraz, Nikolaj Zimic. (2003)
"Boids with a fuzzy way of thinking"

Fuzzy logic approach

- They think that a real bird can not sense the crisp value of a flockmates heading and speed, but it can sense only a relative difference between their headings and speeds.
- They set some linguistic <u>variables</u>:
  - Hd: relative heading difference
  - Sd: relative speed difference
  - SIG: significance of the observed boid's flockmate

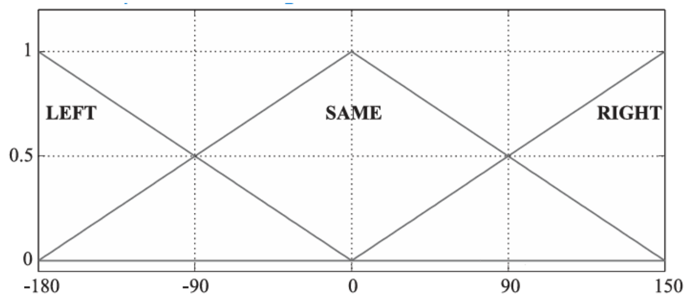


Fig. 1: Linguistic variable *Hd* membership functions.

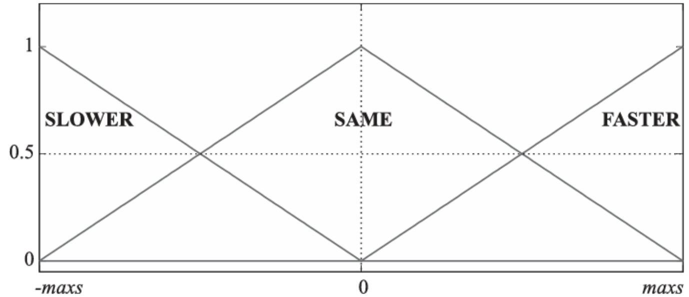


Fig. 2: Linguistic variable *Sd* membership functions.

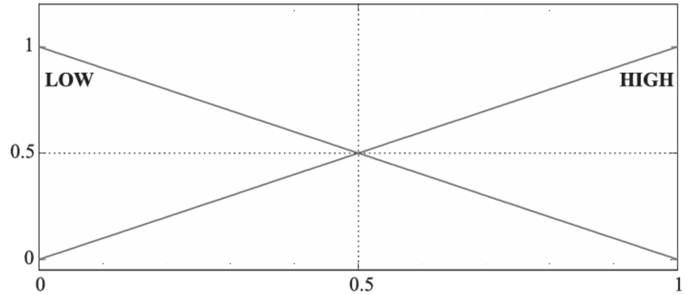


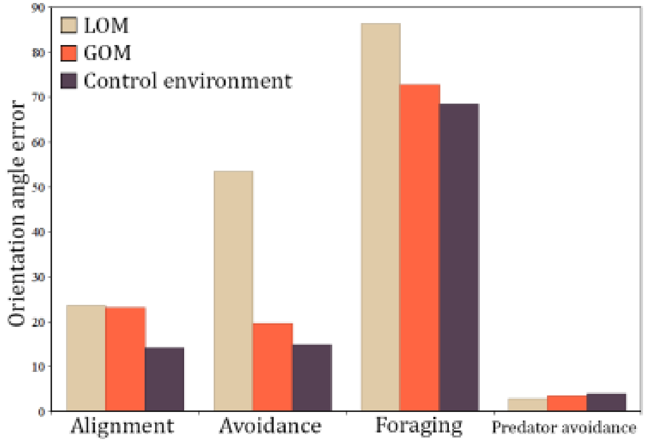
Fig. 3: Linguistic variable *SIG* membership functions.

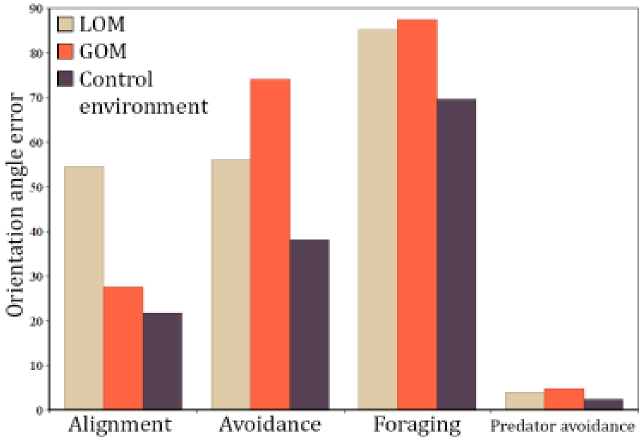
Prey Driven by Neural Networks

Georgi Ivanov, George Palamas. Aalborg University Copenhagen.
"Collective Adaptation in Multi-Agent Systems"

- Prey Behavior: Emergent (Not Programmed)
- Each prey is an independent agent controlled by a neural network.
- Reward System: The prey's AI is not programmed to "group up". It is only programmed to follow these simple rules:
  - +0.5 for foraging (eating food).
  - -1.0 if caught by the predator (the maximum penalty).
  - -0.5 for hitting a wall.

  The prey's AI tries to maximize these points.





Simulating Predator's Characteristics

Kazushi Tsutsui, Ryoya Tanaka, Kazuya Takeda, Keisuke Fujii "Collaborative hunting in artificial agents with deep reinforcement learning"

- Can hunt **alone** or **cooperatively**.
  - Predators may act individually or coordinate loosely in small groups.
- Each agent has a **field of vision**.
  - Determines what prey or flocks can be detected within range and angle.
- When a **flock is detected**, the hunting **process** starts.
  - The hunt follows <u>four stages</u>.

Predator's Hunting Process

Md. Mahbub-Ul Haque, Surid Imam Khan Sur, Rehnuma Binta, Supti Rani Saha "Computer-Generated Artificial Life Model: Algorithm for Hunters Hunting Preys"

- **Target**– locate the flock and selects a target, usually one at the edge or slightly separated.
- **Chase** – accelerates and adjusts its trajectory to intercept, maintaining high-speed pursuit and dynamic path correction based on prey movement.
- **Isolate** – disrupts flock cohesion, forcing the chosen prey away from the group's protection.
- **Terminate** – performs a decisive strike, ending the pursuit if contact is made or restarting the detection phase if the target escapes.

Target → Chase → Isolate → Terminate

Optional extras

R. F. Storms, C. Carere, F. Zoratto, C.K. Hemelrijk "Complex patterns of collective escape in starling flocks under predation"

Predator States:

- Cruise Mode: low-speed patrol used to search for and locate prey flocks.
- Attack Mode: high-speed pursuit activated upon detecting prey.

- Patterns of collective scape under predation.

https://pubmed.ncbi.nlm.nih.gov/30930523/

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