Collective Behaviour Project

Collective Fish Behaviour

A Hydrodynamic Interaction Model

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Goal of the project

Initial Objective:

- Develop a refined fish behavior simulation including hydrodynamics presented in *Model of collective fish behavior with hydrodynamic interactions*, *Fiella et. al. (2018)*
- Aim for accuracy in modeling behavior influenced by environment

Our Improvements:

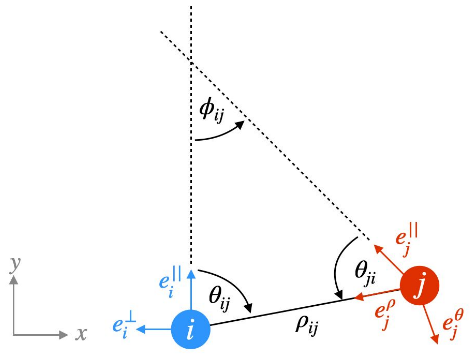
- Enhance the model from the paper with water physics and predator interactions
- Create a realistic, interactive simulation environment

Fish behavioural model

- *Self-Propelled Particle (SPP)* model
- Fish - particle moving with a constant speed
- Attraction factor k_p, alignment factor k_v
- Gaussian rotational noise σ
- New variables

$$I_{||} = k_v \sqrt{\frac{v}{k_p}} \qquad I_n = \sigma (v k_p)^{-\frac{1}{4}}$$

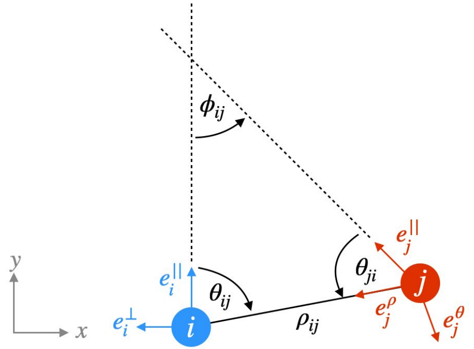
$$I_f = S^{\frac{k_p}{v}}$$



Fish behavioural model - system of equations

$$\dot{r}_i = e_i^{||} + U_i$$

$$\dot{\theta}_i = \langle \rho_{ij} \sin(\theta_{ij}) + I_{||} \sin(\phi_{ij}) \rangle + I_n \eta + \Omega_i$$



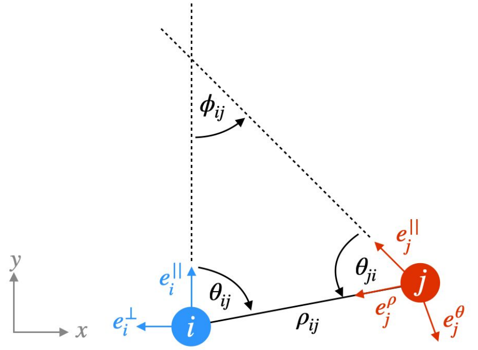
- Drift term

$$U_i = \sum_{j \neq i} = u_{ji}, \quad u_{ji} = \frac{I_f}{\pi} \frac{e_j^{\theta} \sin(\theta_{ji}) + e_j^{\rho} \cos(\theta_{ji})}{\rho_{ij}^2}$$

Fish behavioural model - system of equations (cont'd)

$$\dot{r}_i = e_i^{||} + U_i$$

$$\dot{\theta}_i = \langle \rho_{ij} \sin(\theta_{ij}) + I_{||} \sin(\phi_{ij}) \rangle + I_n \eta + \Omega_i$$



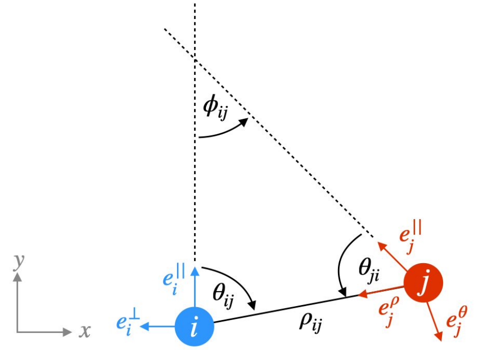
- Standard Wiener process η
- Hydrodynamic-induced rotation

$$\Omega_i = \sum_{j \neq i} e_i^{||} \cdot \nabla u_{ji} \cdot e_i^{\perp}$$

Fish behavioural model - system of equations (cont'd 2)

$$\dot{r}_i = e_i^{||} + U_i$$

$$\dot{\theta}_i = \langle \rho_{ij} \sin(\theta_{ij}) + I_{||} \sin(\phi_{ij}) \rangle + I_n \eta + \Omega_i$$



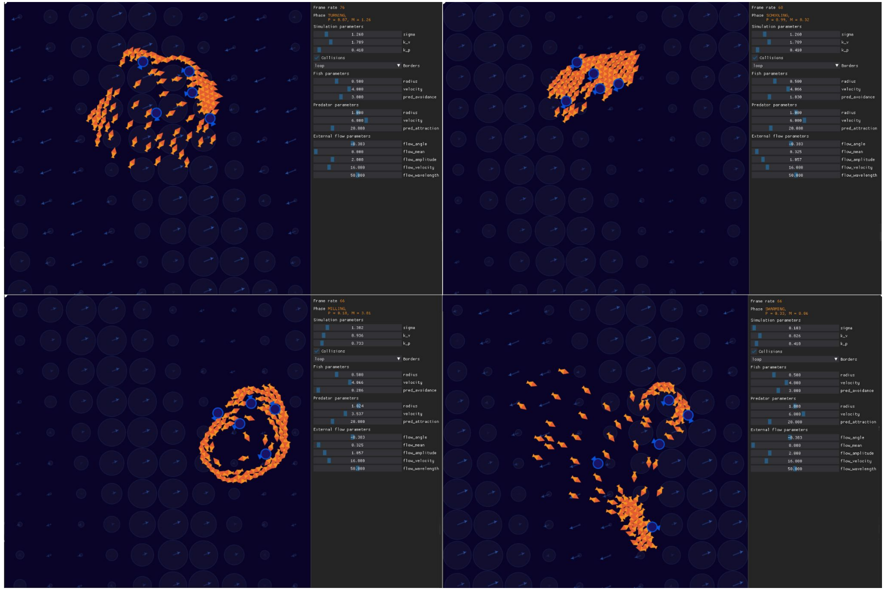
- Averaging over Voronoi neighbours

$$\langle \star \rangle = \frac{\sum_{j \in \nu_i} \star(1 + \cos(\theta ij))}{\sum_{j \in \nu_i} (1 + \cos(\theta ij))}$$

Classification of fish behaviours

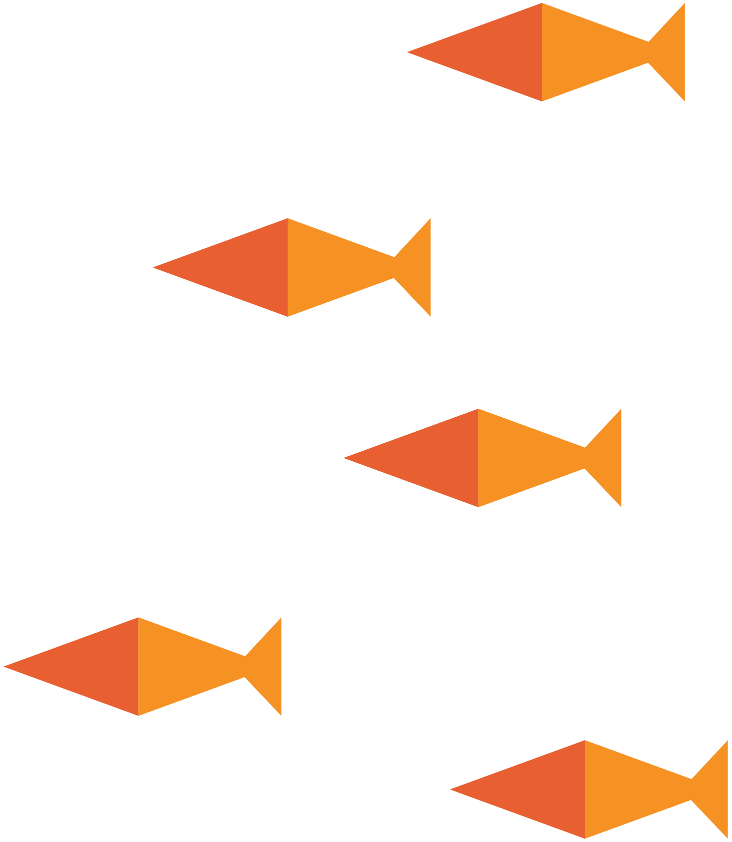
- *Schooling*, *swarming*, *milling*, *turning*
- Classification using new parameters:
  - *Polarization (P)*
  - *Milling (M)*

	$P \leq 0.5$	$P > 0.5$
$M \leq 0.4$	swarming	schooling
$M > 0.4$	milling	turning



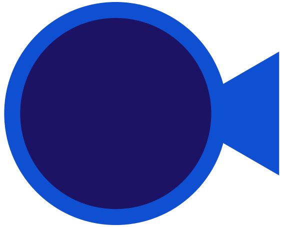
Implementation

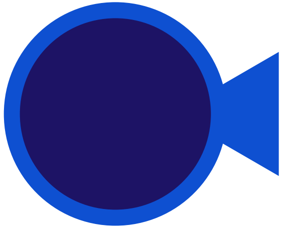
- *Python*
- Libraries: *NumPy, SciPy, DearPyGUI*
- Main goals:
  - Fast simulation
  - Aesthetic design
  - Interactive parameter changing

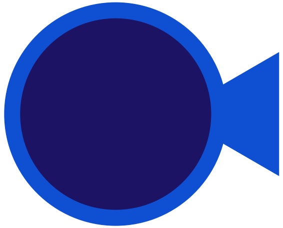


Improvement 1 - predator

- Similar behaviour to the fish
- Moves toward other fish with some attraction factor
- Other fish try to turn away if it’s too close
- Turns away from other predators
- No ability to eat

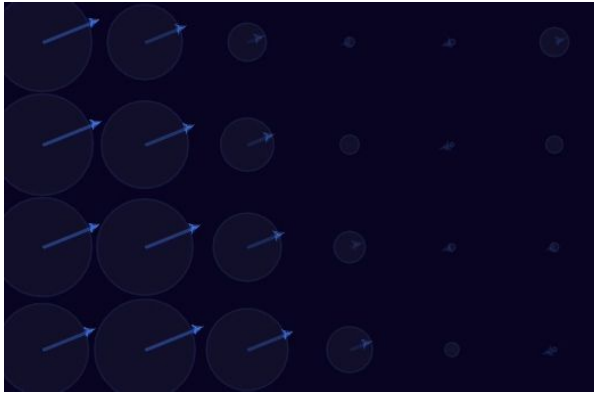






Improvement 2 - external flow

- Simulates natural currents and waves
- Affects fish movement and group dynamics
- Use sine function for simulation
- Calculate the strength at each fish position and move it accordingly
- Apply rotational change with gradient



Achieved Results

Successful Model Replication:

- Replicated complex fish behaviors: swarming, schooling, milling, and turning
- Behaviors classified using Polarization (P) and Milling (M) parameters

Enhanced Realism:

- Integrated like collision avoidance and boundary interactions
- Added predator simulation and external flow dynamics
- An interactive GUI allowing real-time parameter adjustments and observations

Video Demonstration

https://youtu.be/F9MiLQuiUbI?si=J-B8fX5p5xMtAfU6

Improvements and Ideas for Future Projects

- Use better, more efficient GUI library
- Addressing instances where the current model misidentifies fish behavior
- Engage with marine biologists for insights and validation
- Generally content with our approach and methodology