Simulation of zebrafish group behaviour using a stochastic vision-based model

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Overview

Introduction

- **Context:** Based on the research by Collignon et al. (2016)
- **Biological Relevance:**
  - Understanding how individual sensory perception generates collective motion is a fundamental challenge.
  - The zebrafish (*Danio rerio*) is a prime model for studying group behaviour due to its social tendencies and compatibility with controlled experiments.
- **Our Goals:**
  1. **Replicate** the zebrafish model from the original paper.
  2. **Extend the model** to irregularly shaped environments.
  3. Create a performant **interactive simulation**.

Starting point

Title: A stochastic vision-based model inspired by zebrafish collective behaviour in heterogeneous environments
Authors: Bertrand Collignon, Axel Séguret and José Halloy

- **Theoretical Model**: description of the base model we implemented and extended.
- **Experimental data**: real life zebrafish recordings in groups of 1 and 10 in homogeneous and heterogeneous environments.

Starting point – Environments

The original model supports:

- **Homogenous** environments: Fish swimming in an empty square tank.
- **Heterogenous** environments: Fish swimming in a square tank containing spots of interest.

We extended the model to include **irregular** environments with non-square tank geometry.

Theoretical Model

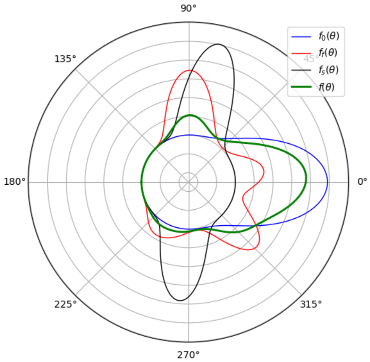
1. **Perception Model**
   - Fish perceive external stimuli (walls, other fish, spots of interest) in a 270° field of view.
   - Each stimuli is given a weight depending on the solid angle it takes up.
2. **Stochastic Decision Making**
   - Speed and orientation are sampled from probability density distributions (PDF) sampled by fish at every time step.
   - Orientation PDF is based on perceived stimuli.
   - Speed PDF is based on data from real zebrafish recordings.

Orientation PDF

The full orientation PDF f is a composite of the following distributions:

- f_0 - basic-swimming or wall-following behaviour if close to wall,
- f_f - influence of other perceived fish,
- f_s - influence of perceived spots of interest.

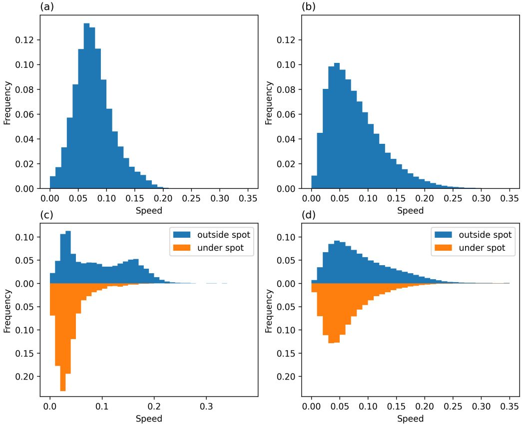
Distribution parameters such as dispersion and weights were determined experimentally.



Speed PDF

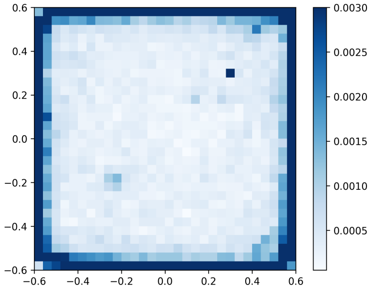
Speed PDFs extracted from real life zebrafish recordings.

- (a, b) homogenous environment with 1 and 10 zebrafish
- (c, d) heterogenous environment with 1 and 10 zebrafish



Presence probability

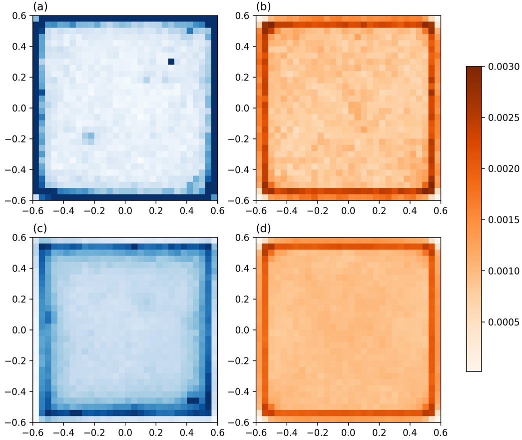
- To validate the correctness of our model and orientation PDF parameters we ran simulations and compared presence probabilities with real life recorded zebrafish data.
- **Presence probability**: Probability a fish is located at a specific location at any given time.



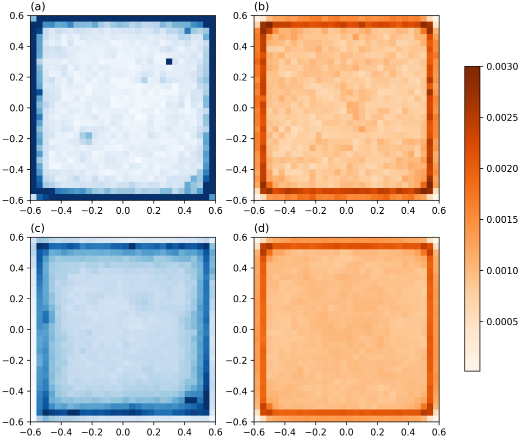
Homogenous environment

Presence probabilities in an empty homogenous environment:

- (a, c) recordings of 1 and 10 real zebrafish.
- (b, d) simulations of 1 and 10 fish.



Heterogenous environment



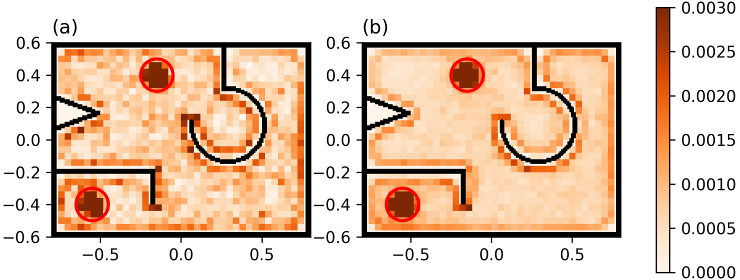
Presence probabilities in a heterogenous environment with two spots of interest:

- (a, c) recordings of 1 and 10 real zebrafish.
- (b, d) simulations of 1 and 10 fish.

Extension to irregularly shaped environments

- Irregular environments contain walls of any shape and configuration.
- We represented the walls using a binary grid.
- To detect wall tangents that fish can follow when close to walls we implemented a ray-casting algorithm:
  1. cast multiple rays radially around the fish
  2. record distance when each ray intersects a wall
  3. group continuous angular segments of rays which collide with walls
  4. calculate two possible tangential movement directions for each wall segment.

Irregular environment



Presence probabilities in an irregular environment with two spots of interest:

- (a, b) recordings of 1 and 10 real zebrafish.

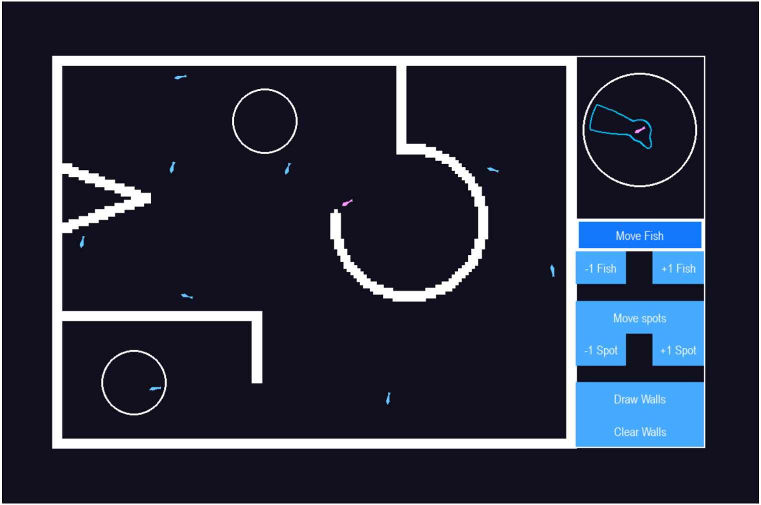
Simulation interactivity

Alongside extending the model to irregularly shaped environments we also created an interactive simulation in pygame with the following features:

- add or remove fish,
- add or remove spots of interest,
- move fish or spots of interest by dragging,
- orientation PDF display which displays the influence of the surrounding stimuli on the currently selected / last dragged fish,
- draw walls to create irregular geometry.

To make the simulation more performant we approximated perceived solid angle calculations with fitted functions.

Interactive simulation



Conclusion & Future Work

Conclusion

- Successfully implemented the original model.
- Validated by presence probability.
- Upgraded to allow irregular environments.
- Implemented interactive simulation.

Future Work

- **More stimuli:** Introducing more stimuli to the environment, such as food.
- **Irregular environment experiments:** Acquiring real zebrafish recordings in irregularly shaped environments to validate our model.