# Experimental analysis and modelling of the behavioural interactions underlying the coordination of collective motion and the propagation of information in fish schools

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# Summary

Collective motion is ubiquitous in fish. Large groups may comprise thousands to millions of individuals. However, it is not yet understood what are the local interaction rules that underlie these collective patterns.

In this thesis, we investigate in a small gregarious fish, the rummy-nose tetra (*Hemigrammus rhodostomus*), the mechanisms underlying both the coordination of motion and the propagation of information in their schools. To discover the connection between individual behaviour and patterns at the collective level, we follow an approach that tightly combines experiments and modelling.

The first part of the thesis is dedicated to the behavioural mechanisms underlying the coordinated swimming in these schools. For this, we analysed the motion of a single individual and pairs of individuals swimming freely in a circular arena. *H. rhodostomus* has a burst-and-coast swimming style. This consists of sudden changes of heading combined with brief accelerations followed by quasi-passive, straight decelerations. We segmented their trajectories on the basis of this intermittent swimming mode. This segmentation determined the analysis of experimental data and the design of the model. We developed a new method to measure and disentangle the interactions between a fish and the wall and between pairs of fish. We tested these findings with a model derived from physical analogies and symmetry considerations. Our results support the presence of interactions among fish based on the coexistence of attraction and alignment.

We also investigated for fish swimming in a ring-shaped tank how an individual integrates the information coming from several other fish and from obstacles in its neighbourhood. For this, we develop a computational model based on maps of behavioural actions that were extracted from empirical data. We tested in this model whether the properties of schools at the global-level were reproduced when fish reacted only to the strongest stimulus they perceived. We rejected this for observations in groups of 5 fish.

The second part of the thesis is dedicated to the analysis of the propagation of information in reaction to internal and external perturbations, in schools of *H. rhodostomus.* The internal perturbations concern spontaneous collective U-turns occurring in a ring-shaped tank. The global properties of the propagation came from empirical data of group sizes with 1 to 20 fish. We formulate an Ising-spin model that integrates both asymmetrical interactions among fish and the tendency of individuals to follow the majority of their neighbours. The model shows that local social conformity may be underlying both the dynamics observed during the collective U-turns and the sharp decrease of the frequency of collective U-turns as the size of the group increases.

Finally, we develop a preliminary experimental method to induce controlled external perturbations with the objective to investigate the propagation of information during disturbances. We show that aversive conditioning (i) can be performed in this species, (ii) triggers collective escape reactions and (iii) transfers from the training condition to a new experimental set-up. These results come from a training in which a green light elicits an escape reaction in conditioned fish. Our findings suggest that the proportion of conditioned individuals in a group is critical in triggering collective escape reactions.