Closed-loop feedback system based on virtual reality for real-time analysis of interactions in fish schools

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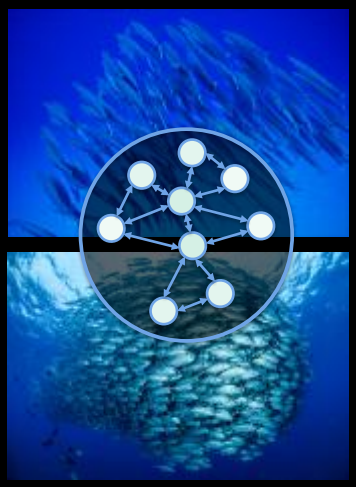
Consortium and research teams

Institutions/Laboratories	Teams	People	Position	Expertise
Centre de Recherches sur la Cognition Animale Centre de Biologie Intégrative CNRS UMR 5169	Collective Animal Behavior	M. Combe R. Escobedo M. Moreau G. Theraulaz T. Xue L. Xu	IE CNRS Post-doc IE CNRS DR CNRS PhD PhD	*Quantitative ethology, Behavioral analysis, Real-time video-tracking and trajectory analysis, statistical analysis and simulation of IBM models*
Laboratoire de Physique Théorique CNRS UMR 5152	Statistical physics	C. Sire	DR CNRS	*Data analysis, computational modeling, Development of analytical and numerical methods*
Institut de Recherches en Informatique de Toulouse CNRS UMR 5505	Reality Expression – Artificial Life	R. Bastien S. Cussat-Blanc J.-P. Jessel H. Luga S. Sanchez	Post-doc MdC UPS Pr UPS Pr UPS MdC UPS	*Hardware Virtual Reality setup, Development and animation of 3D realistic models*
Universität Freiburg	Straw Lab	A. Straw	Pr Universität Freiburg	*Real-time video-tracking, Development of closed-loop virtual reality systems*

Goals of the research project

- General framework of the ANR-funded project (started in January 2021): deciphering and modeling the social interactions involved in collective behaviors observed in animal societies
- Building a closed-loop system based on virtual reality to study the interactions between fish involved in the coordination of swimming in a school
- Understanding how fish combine multiple local interactions with their neighbors to coordinate their motion when travelling in groups (i.e. who are the influential neighbors and how a fish integrates the information from its influential neighbors



Understanding the mechanisms underlying collective intelligence

Complex systems with emergent properties

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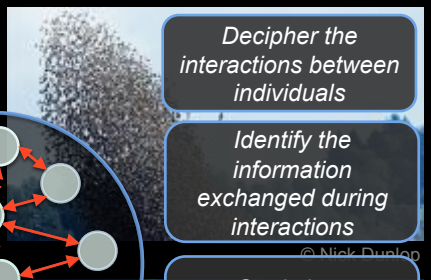

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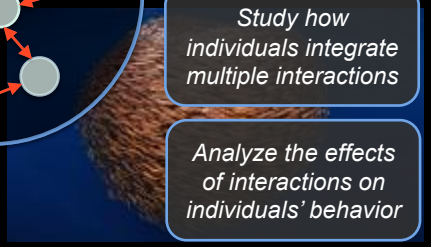
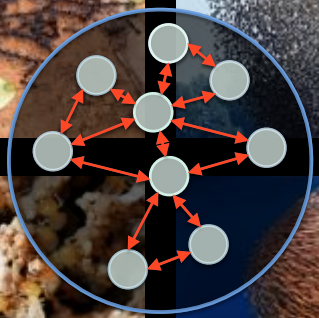




Decipher the interactions between individuals

Identify the information exchanged during interactions

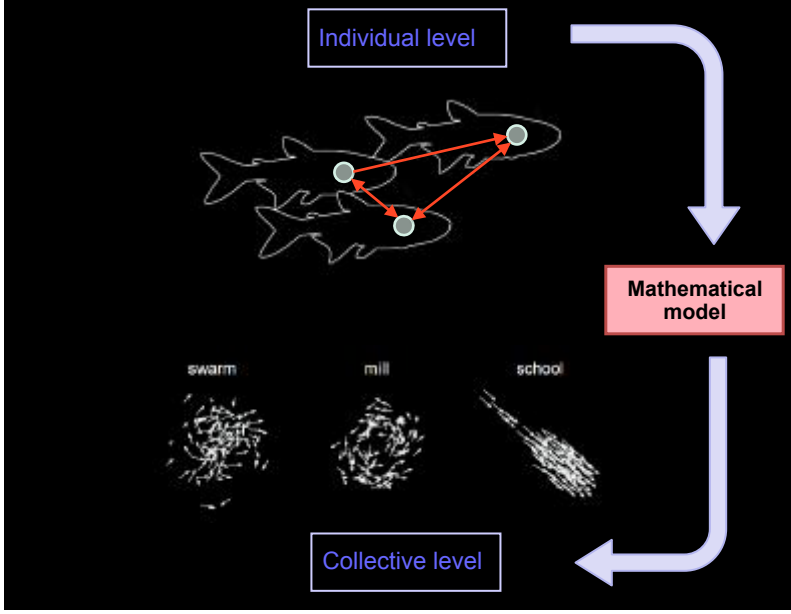
Study how individuals integrate multiple interactions

Analyze the effects of interactions on individuals' behavior

Garnier, S. *et al.*, *Swarm Intelligence* (2007)

How do properties emerge at the group level?

Quantifying and modeling individual behavior and social interactions



Collective motion in fish schools

Study species: the Rummy-nose tetra

Hemigrammus rhodostomus

Average body length: 31mm

Collective motion in fish schools

Automated tracking of animal movement and behaviour

Hemigrammus rhodostomus

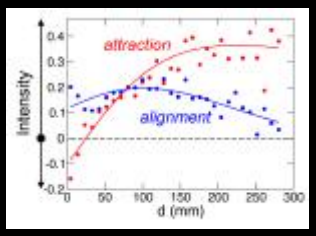
Distance *Angular position* *Relative heading*

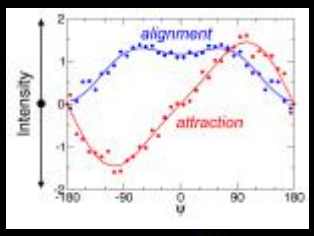
Pérez-Escudero, A. *et al.*, *Nat. Methods* (2014)
Lecheval, V. *et al.*, *Proc. R. Soc. B* (2018)

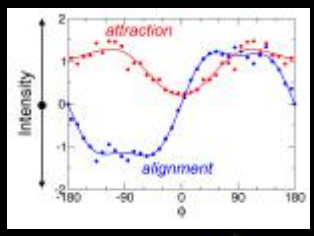
Measuring and modeling social interactions

Attraction and alignment between two fish

Distance *Angular position* *Relative heading*







Calovi, D.S. *et al.*, *PloS Comput. Biol.* (2018)
Escobedo, R. *et al.*, *Philos Trans R Soc Lond B Biol Sci.* (2020)

Measuring and modeling social interactions

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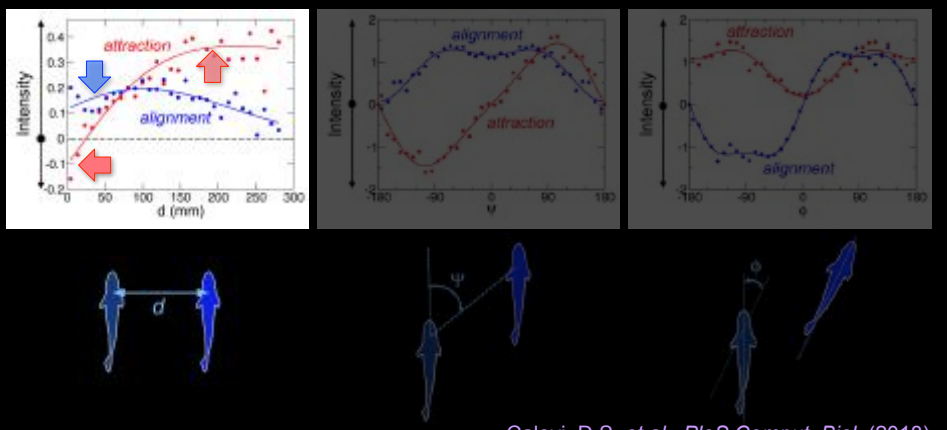

Calovi, D.S. *et al., PloS Comput. Biol.* (2018)
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Measuring and modeling social interactions

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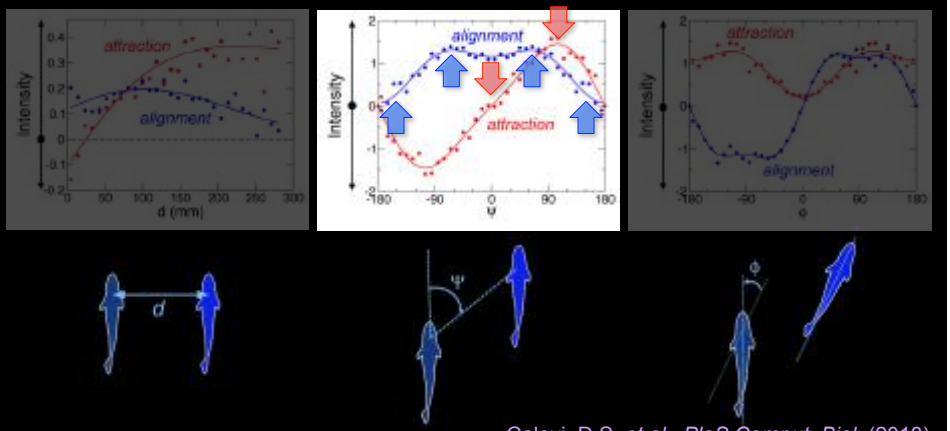
Distance *Angular position* *Relative heading*

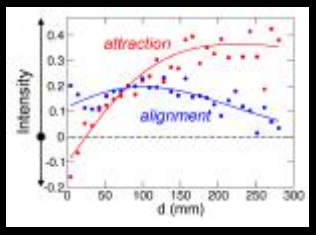


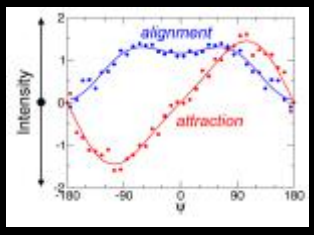
Calovi, D.S. *et al., PloS Comput. Biol.* (2018)
Escobedo, R. *et al., Philos Trans R Soc Lond B Biol Sci.* (2020)

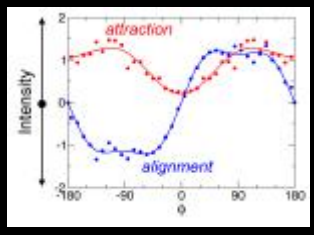
Measuring and modeling social interactions

Modeling the interactions between two fish

Distance | *Angular position* | *Relative heading*







$$F_{At}(d) \propto \frac{(d-a)/l_{At}}{1+(d/l_{At})^2}$$

$$F_{Al}(d) \propto \left(\frac{d}{l_{Al}}+c\right)\exp[-(d/l_{Al})^2]$$

$$O_{As}(\psi) \propto \sin(\psi)[1-0.33\cos(\psi)]$$

$$E_{As}(\psi) \propto 1+0.60\cos(\psi)-0.32\cos(2\psi)$$

$$E_{Ar}(\Delta\phi) \propto 1+0.48\cos(\Delta\phi)-0.31\cos(2\Delta\phi)$$

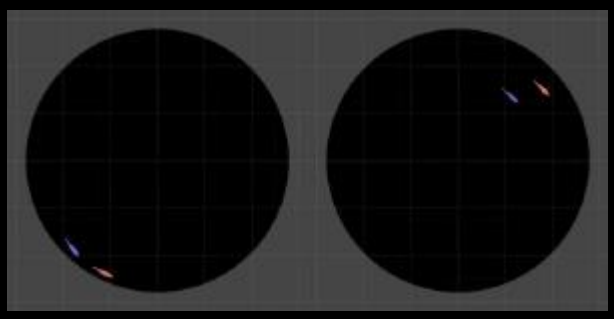
$$O_{Ar}(\Delta\phi) \propto \sin(\Delta\phi)[1+0.30\cos(2\Delta\phi)]$$

Calovi, D.S. *et al., PloS Comput. Biol.* (2018)

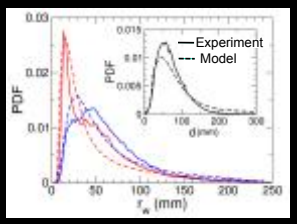
Modeling interactions between pairs of fish

Comparison between experiments and simulations

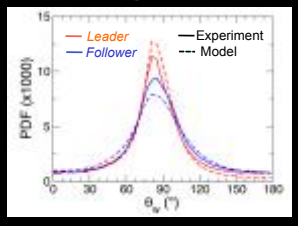
Experiment | Model



Distance of fish to the wall and distance between fish



Relative angle to the wall



- The model qualitatively and quantitatively reproduces the key features of the motion and spatial distributions of fish observed in experiments

Calovi, D.S. *et al., PloS Comput. Biol.* (2018)

Combining interactions with multiple neighbors

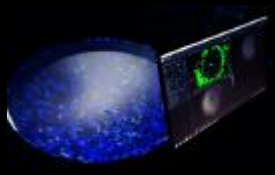
The selective attention of fish to their neighbors

- To coordinate their movements rummy nose tetras only interact with the most or the two most influential neighbors
- These most influential neighbors are those that have the strongest contribution to the heading variation of the focal fish
- Each fish must acquire only a minimal amount of information about the behavior of its neighbors for coordination to emerge at the group level

Jiang, L. *et al. PloS Comput. Biol.* (2017)
Lecheval, V. *et al.*, *Proc. R. Soc. B* (2018)
Lei, L. *et al., PloS Comput. Biol.* (2020)

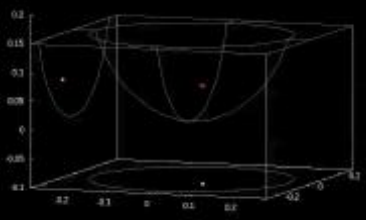
Description of the research project

- Building a closed-loop system based on virtual reality to measure and analyze in real-time the interactions between fish and their effects on individual behavior
- The closed-loop system (1) will bring new insights about the visual information used by fish to control their motion and how fish combine multiple information sources in the environment and (2) will make it possible to build and validate a fish school model integrating multiple interactions between fish

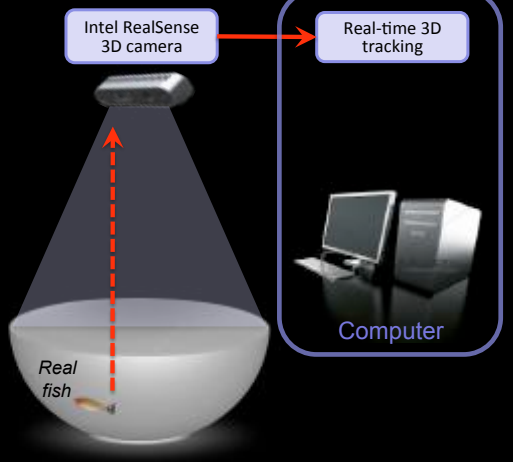


Description of the research project

- Real-time 3D tracking of fish in the immersive VR platform

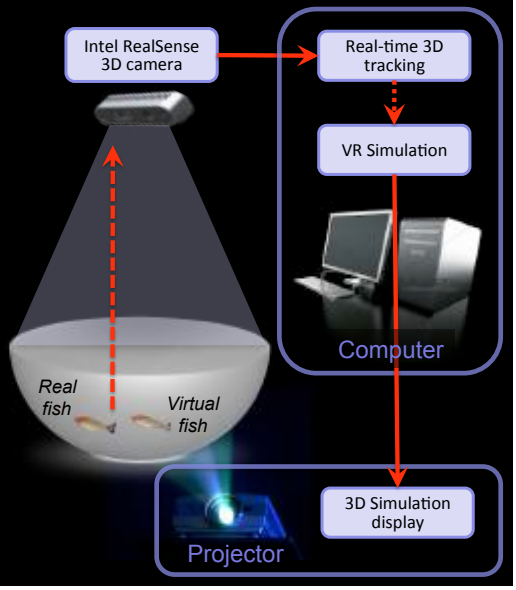


Speed x 4



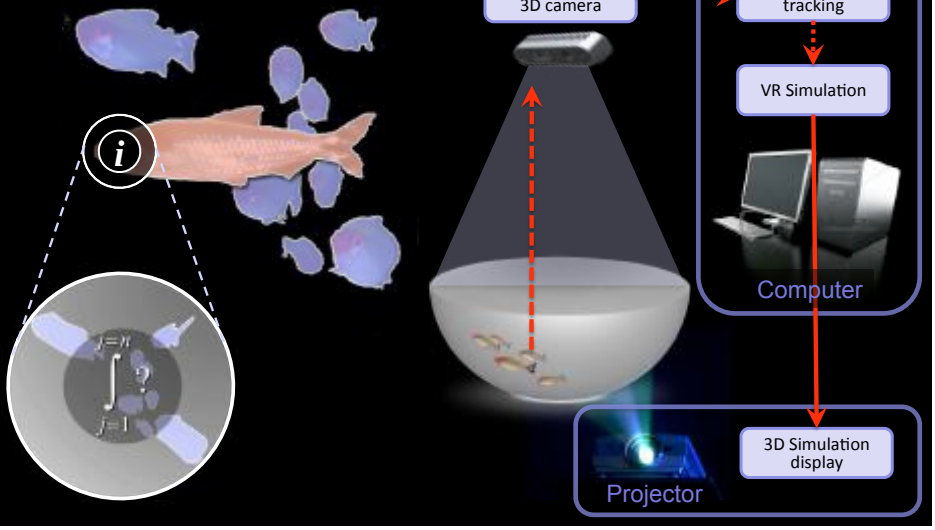
Description of the research project

- Behavioral model and real-time control of the Virtual Fish
- Validation of the behavioral model through direct interactions between a Real fish and a Virtual fish (Measuring the impact of the distance, the speed and the relative orientation of a virtual fish on the behavior of a real fish)



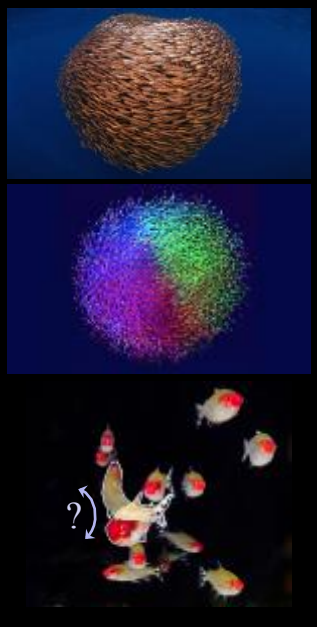
Description of the research project

- Testing hypotheses on the combination and integration of influence exerted by multiple virtual neighbors on a fish



Expected impacts and outcomes of the project

- To understand the coordination mechanisms involved in collective movements in different species of fish and to develop quantitative and predictive models
- To acquire new knowledge about 1) the behavioral and cognitive processes involved in decision-making in a collective context and 2) the visual information used by fish to control their movement



Expected impacts and outcomes of the project

- To produce a proof of concept prototype for developing similar systems based on virtual reality to investigate behavioral and cognitive processes in other social animals (rats, mice, human crowds)

Projet ALTHEA, 80IPrime CNRS (2020-2023)

Expected impacts and outcomes of the project

- To provide new methods for designing bio-mimetic distributed control algorithms in swarm robotics (swarms of autonomous micro-robots and drones capable of self-organizing and cooperating)