Neuronal model for startling coupled with a collective behavior model

Andrej Warkentin and Pawel Romanczuk
Institute of Theoretical Biology, Department of Biology, Humboldt Universität zu Berlin
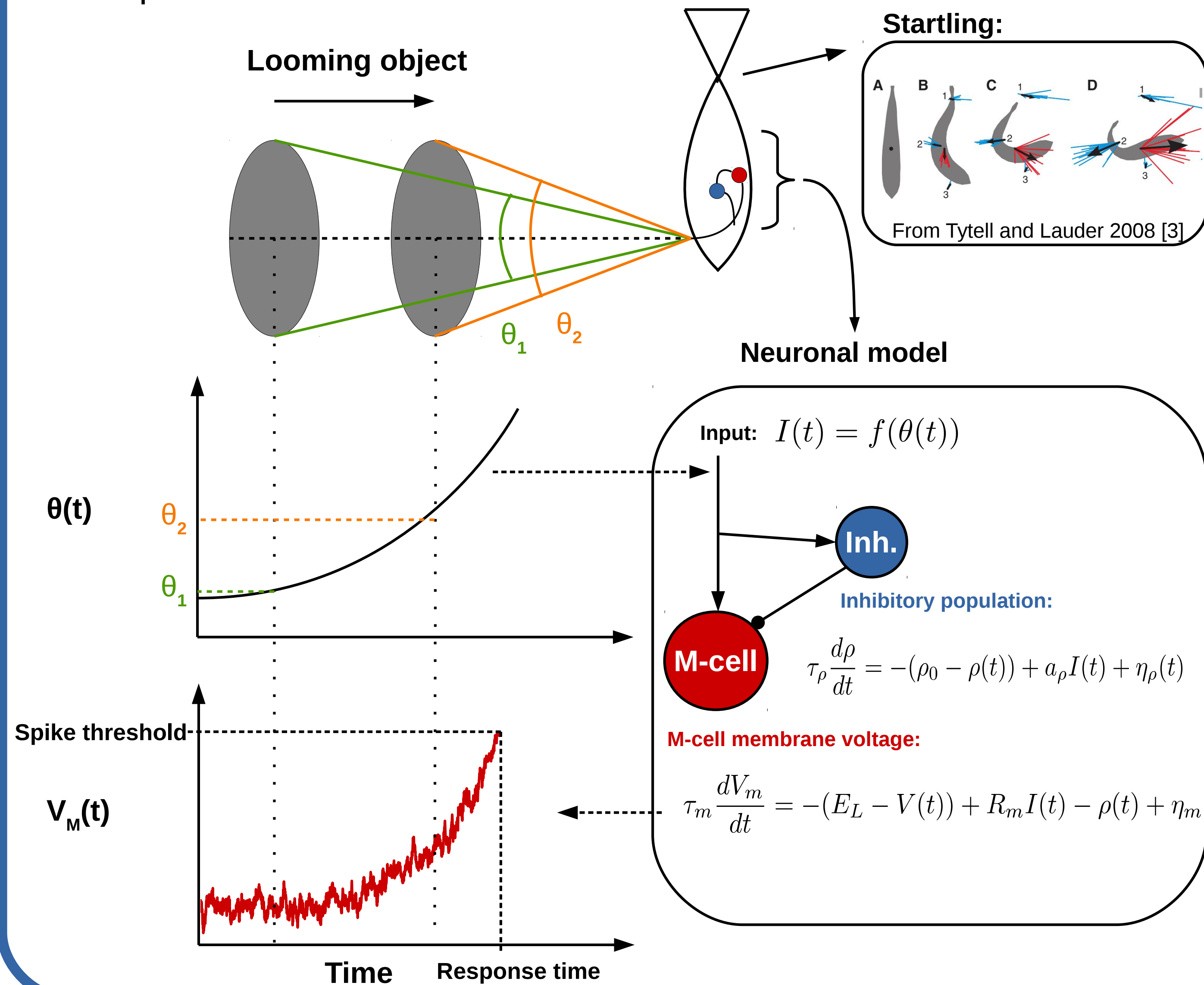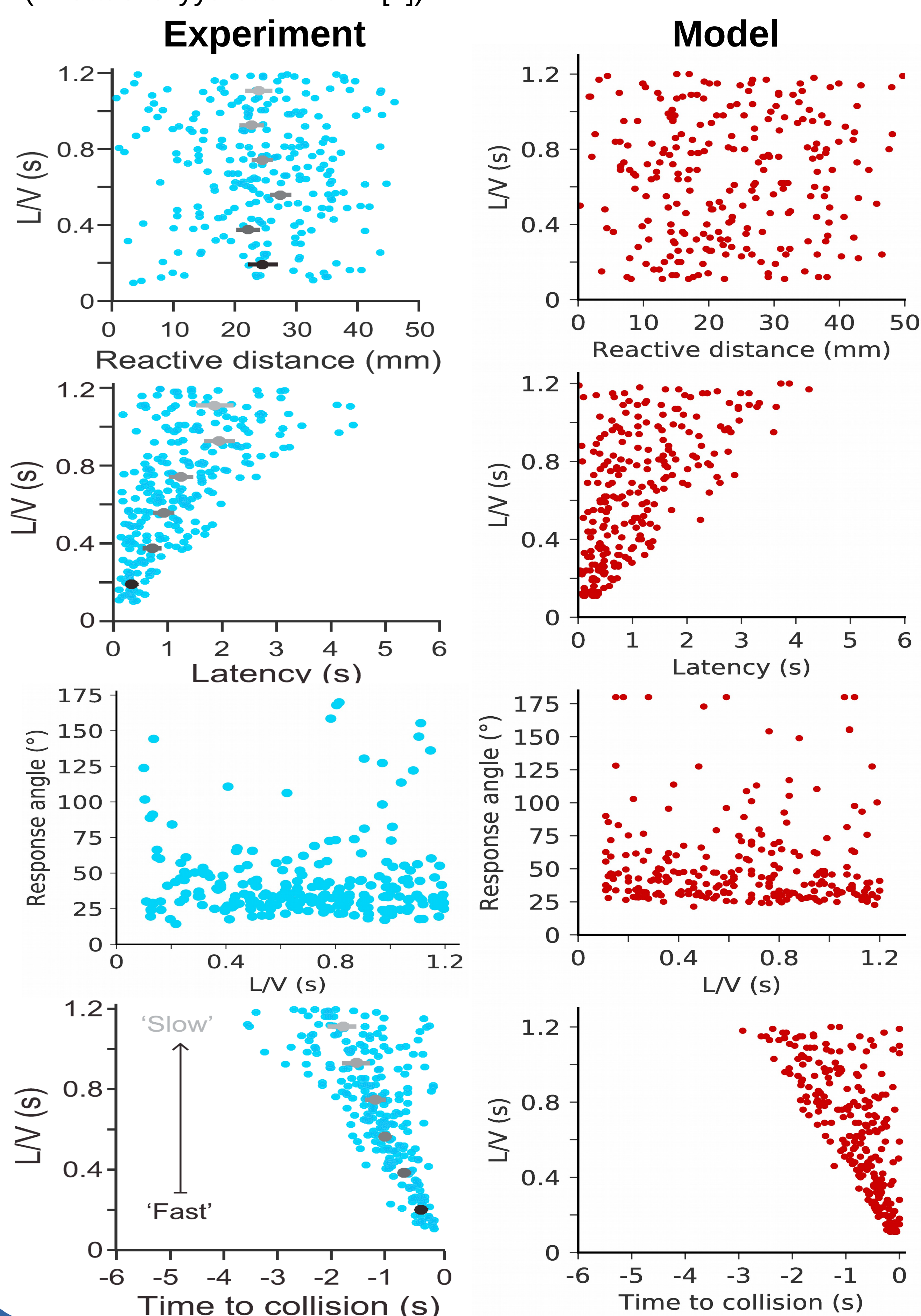Bernstein Center for Computational Neuroscience, Berlin

1) Introduction & Neuronal model

• The Mauthner-cell (M-cell) circuit has been identified to be responsible for the startle response in fish but we still lack a mechanistic understanding
• The startle response is known to spread in fish schools dependent on the network structure (Rosenthal et al. 2015 [1]).
• Here we:
1) Find a neuronal model that reproduces behavior in a visual looming stimulus experiment (Bhattacharyya et al. 2017 [2])
2) Combine the neuronal model with a collective behavior model to explore the initiation of startles in a fish school

Looming object

Startling:

From Tytell and Lauder 2008 [3]

Neuronal model

Input: $I(t) = f(\theta(t))$

Inh.

Inhibitory population:
$$\tau_\rho \frac{d\rho}{dt} = -(\rho_0 - \rho(t)) + a_\rho I(t) + \eta_\rho(t)$$

M-cell

M-cell membrane voltage:
$$\tau_m \frac{dV_m}{dt} = -(E_L - V(t)) + R_m I(t) - \rho(t) + \eta_m$$

$\theta(t)$

Spike threshold
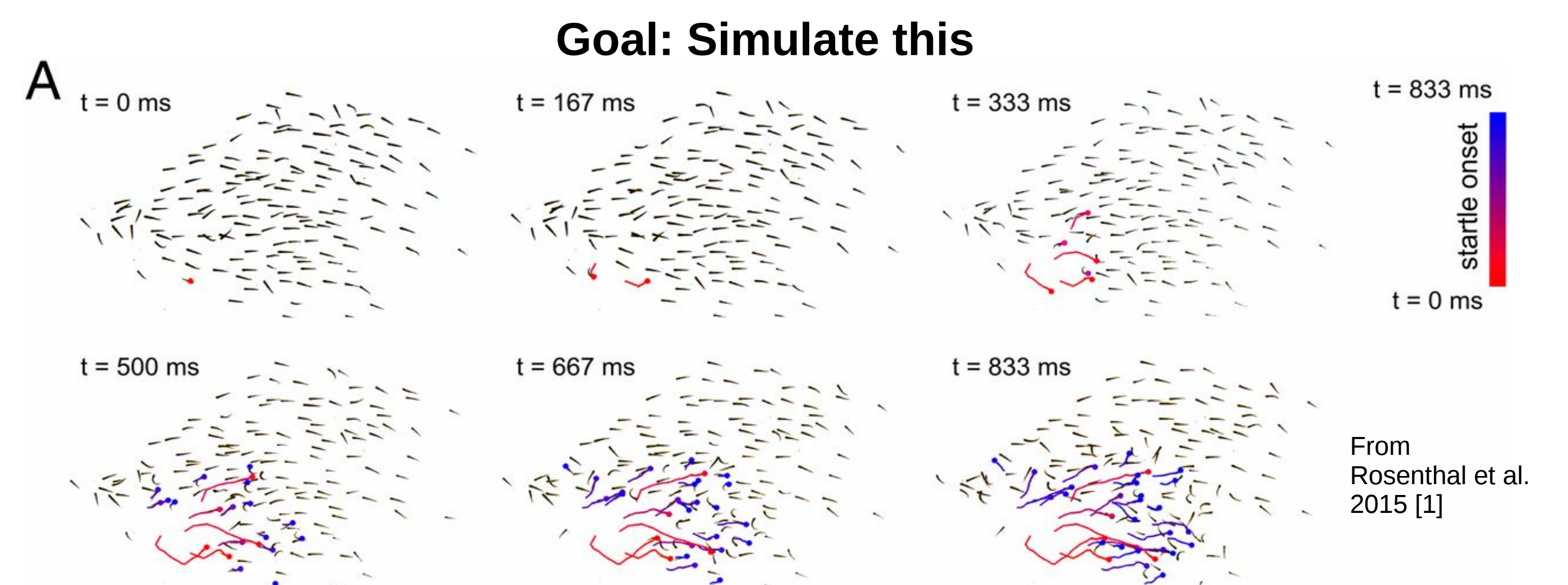
$V_M(t)$

Time — Response time

2) Neuronal model reproduces experimental response properties

Using the instantaneous visual angle as input for the neuronal model we can reproduce the patterns of response distance, response time and time-to-collision as well as the response angle that were found in an experiment with different approach speeds of a looming stimulus (Bhattacharyya et al. 2017 [2]).

Experiment   **Model**

3) Collective behavior model

Goal: Simulate this

A t = 0 ms   t = 167 ms   t = 333 ms   t = 833 ms
t = 500 ms   t = 667 ms   t = 833 ms

startle onset   t = 0 ms

From Rosenthal et al. 2015 [1]

Brownian motion   +   Social forces   +   Startle mechanism
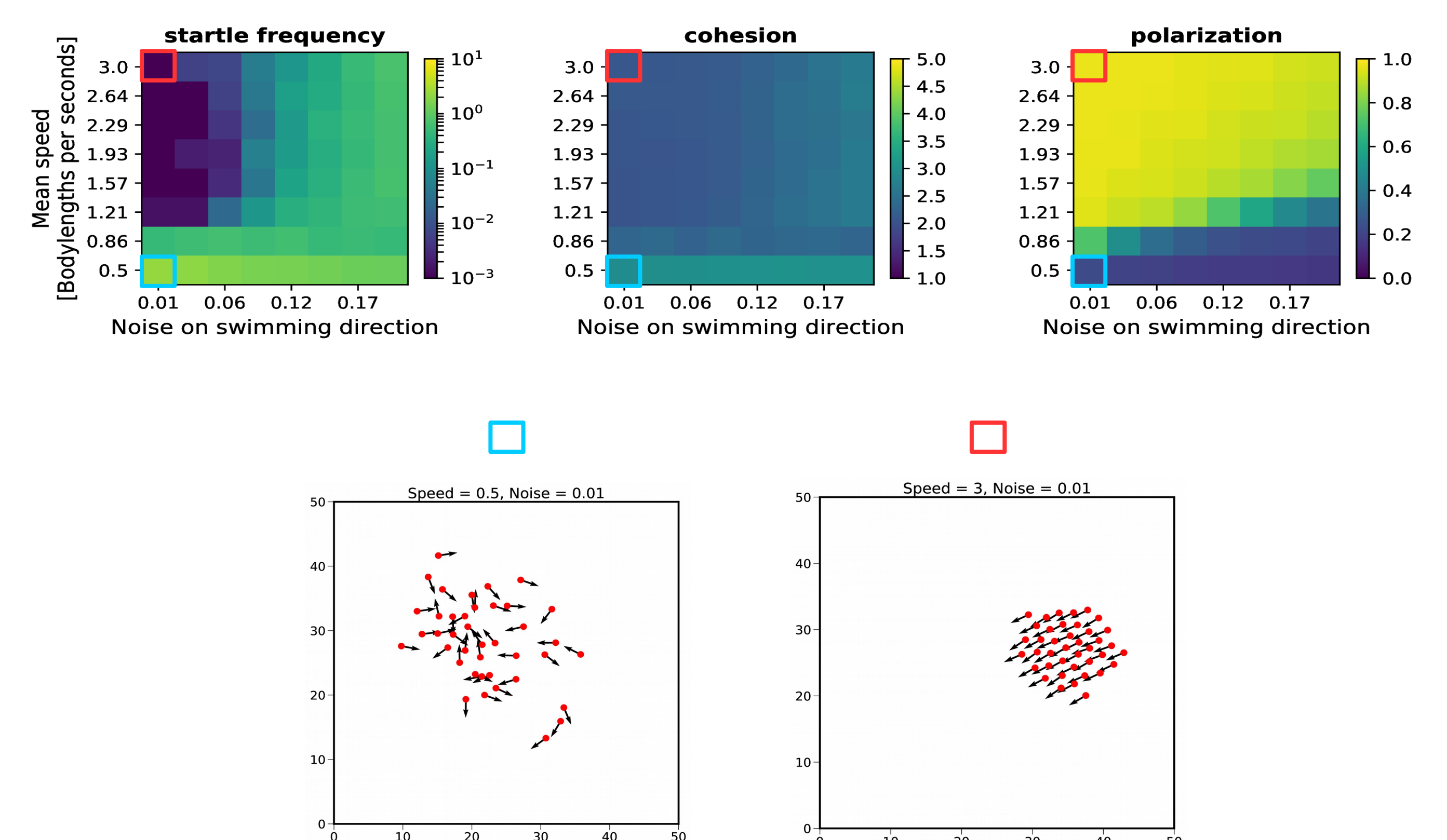
$$\frac{d\vec{r_i}}{dt} = \vec{v_i}(t)$$

$$\vec{v_i}(t) = \begin{pmatrix} s_i \cos(\varphi_i(t)) \\ s_i \sin(\varphi_i(t)) \end{pmatrix}$$

$$\frac{ds_i}{dt} = \alpha (\mu_s - s_i) + F_{i,s} + \eta_{i,s}$$

$$\frac{d\varphi_i}{dt} = \frac{1}{s_i + c_s} (F_{i,\varphi} + \eta_{i,\varphi})$$

Inh.

M-cell

4) Collective behavior results

startle frequency   cohesion   polarization

Mean speed [Body lengths per seconds]

Noise on swimming direction

Speed = 0.5, Noise = 0.01   Speed = 3, Noise = 0.01

5) Discussion & Outlook

• A simple neuronal model can reproduce response properties of fish in a looming stimulus experiment
• We are able to combine the neuronal model with a individual-based collective behavior model in order to analyze startle initation in fish schools
• First results suggest that the polarization of the school determines the startle frequency but further investigation is needed

Outlook Neuronal Model:
• How is the visual input related to the visual field of the fish?
• What happens if more than one stimulus is present at the same time?
• Can we also explain experimental response probabilities?

Outlook Collective Behavior Model:
• Are startling frequency and polarization also correlated in a temporal manner?
• How is the startling frequency related to the cohesion of the school?

6) References & Links

[1] Rosenthal et al. 2015, PNAS, 112:4690–4695, doi:10.1073/pnas.1420068112
[2] Bhattacharyya et al. 2017, Current Biology, 27 (18):2751 – 2762.e6, doi:10.1016/j.cub.2017.08.012
[3] Tytell and Lauder 2008, J. of Exp. Biology, 211(21):3359–3369, doi:10.1242/jeb.020917.

Github repository: https://github.com/awakenting/master-thesis