Quantifying collective animal behaviour

David J. T. Sumpter

Mathematics Department, Uppsala

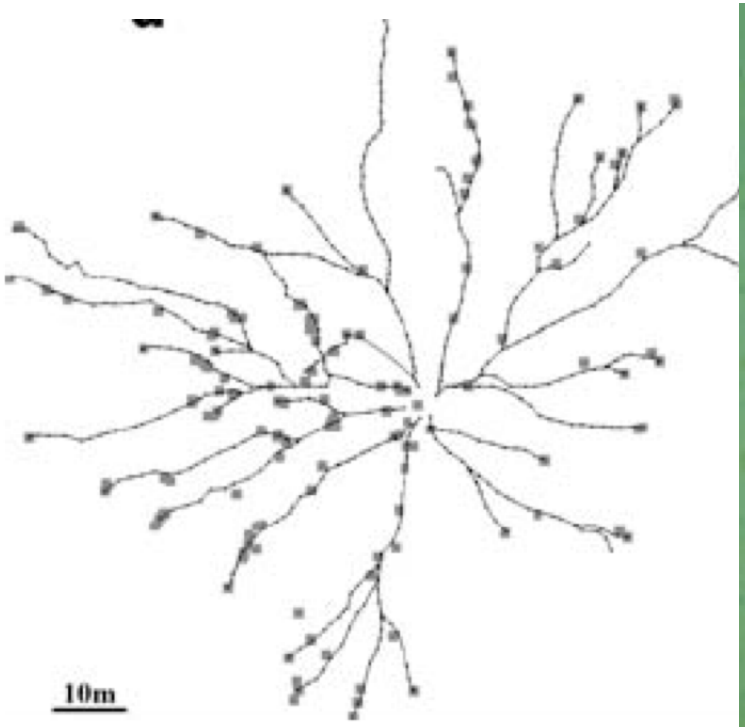
Work with: Ashley Ward, Teddy Herbert-Read and Jens Krause (Berlin/Sydney)

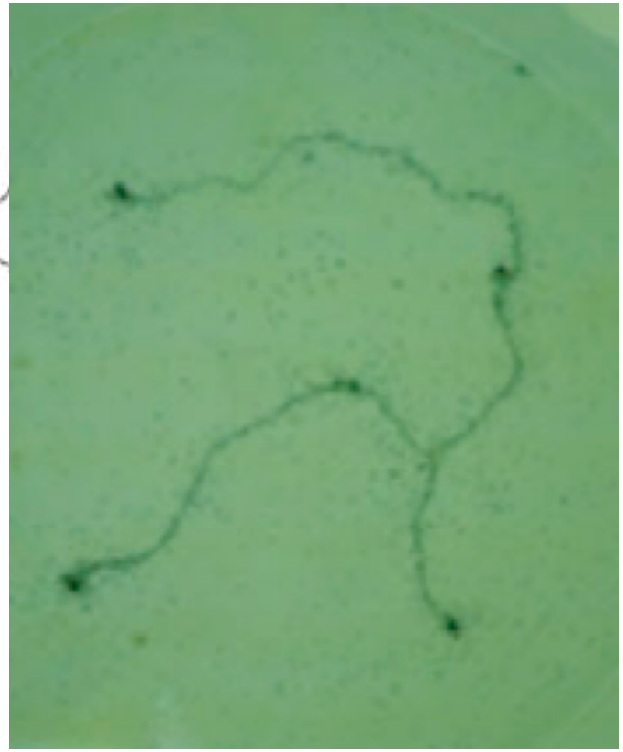
Daniel Strömbom, Arianna Bottinelli, Richard Mann & Andrea Perna (Uppsala)

Funding: European Research Council

STARFLAG project: http://angel.elte.hu/starling/index.html

Slime mould and Ant Networks





Tero et al, 2010, *Science*

Buhl et al, 2009, *Behavioral Ecology and Sociobiology*

Latty et al, 2011, *Royal Scoiety Interface*

Collective behaviour
What questions do we ask?

Collective behaviour
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- Group decision-making.
- Information transfer.
- Collective motion.

Collective behaviour
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- **Group decision-making.**
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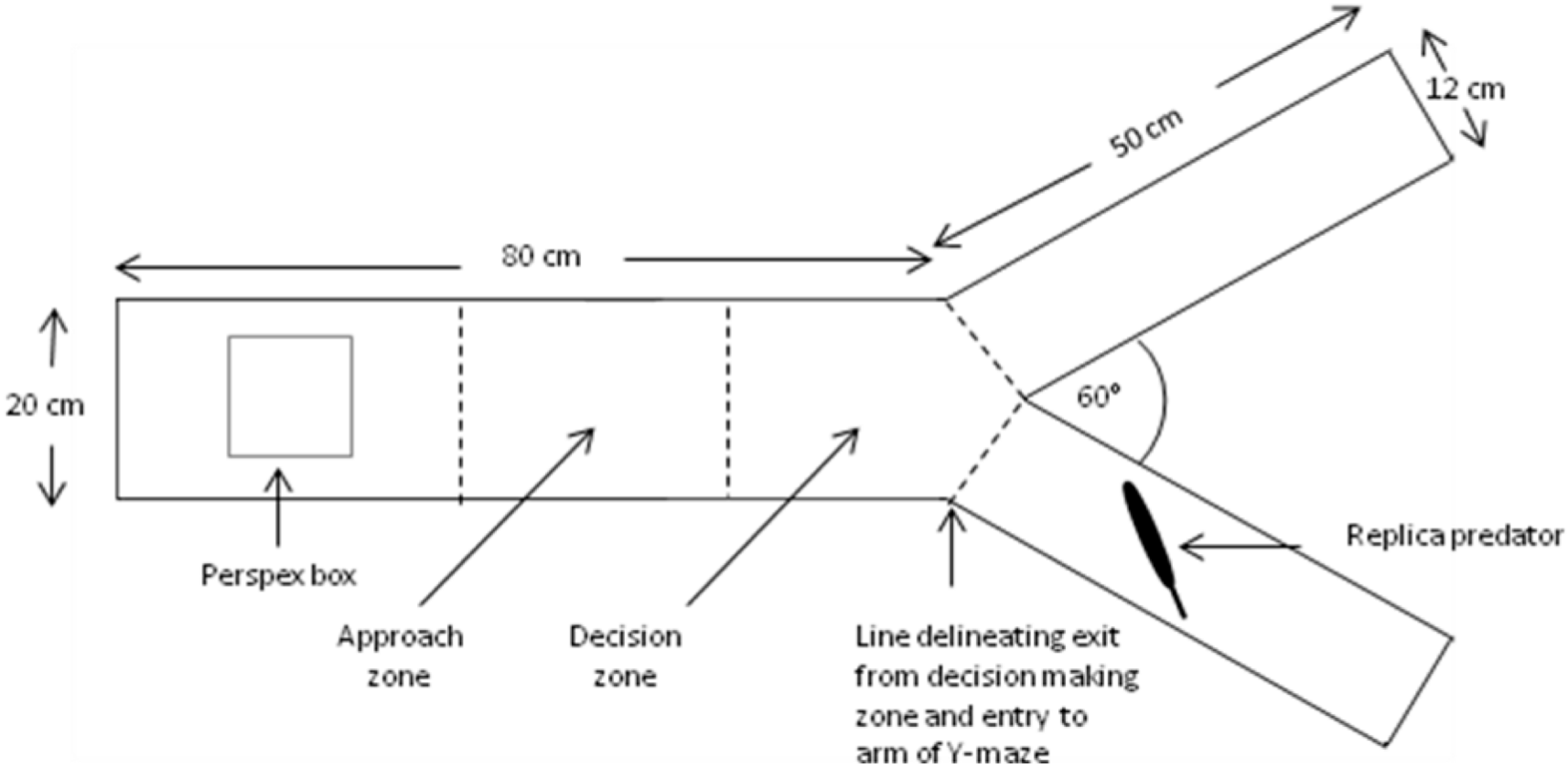
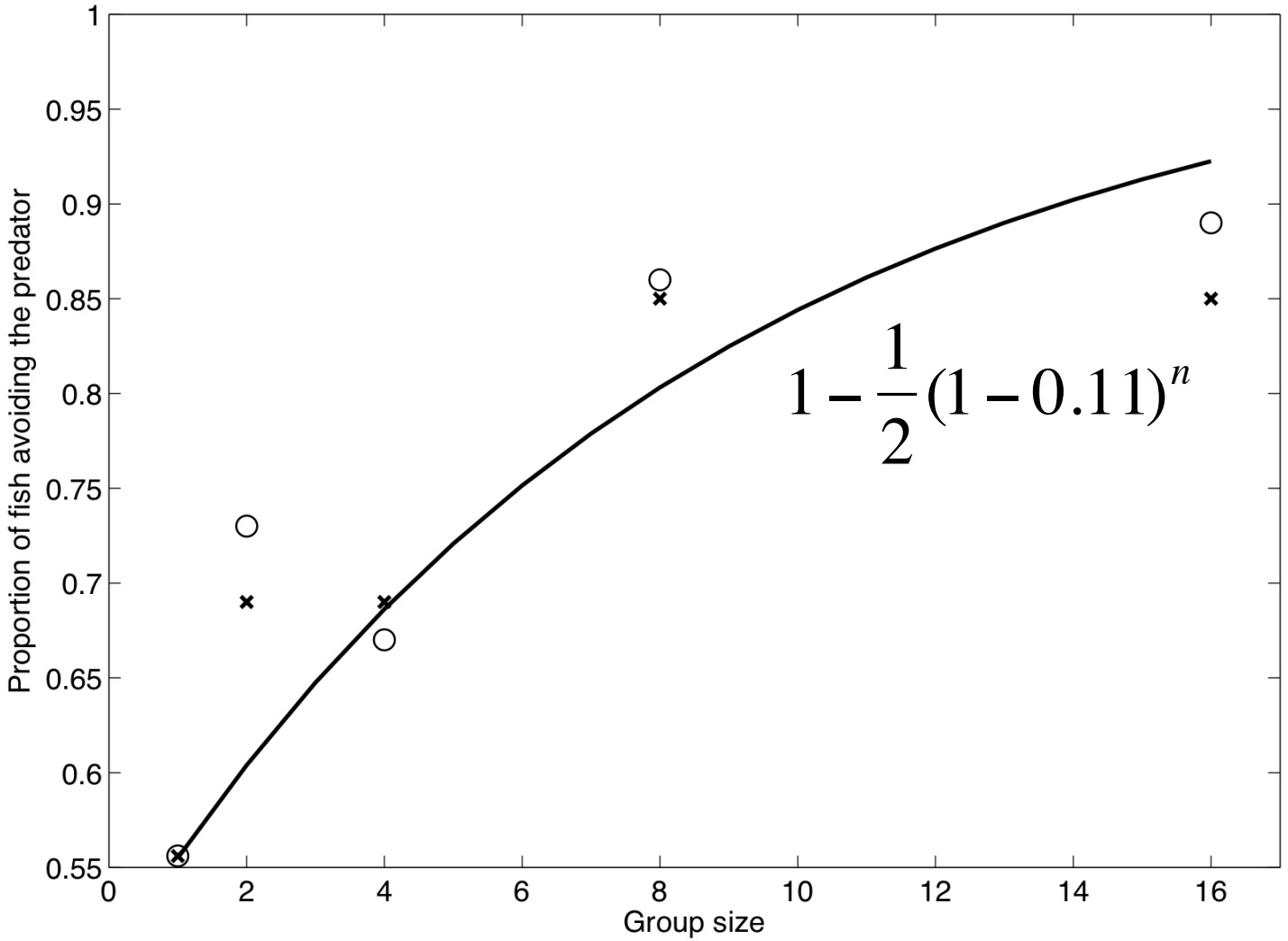
Predator detection



Ward et al. (2011), *Proceedings of the National Academy of Sciences*

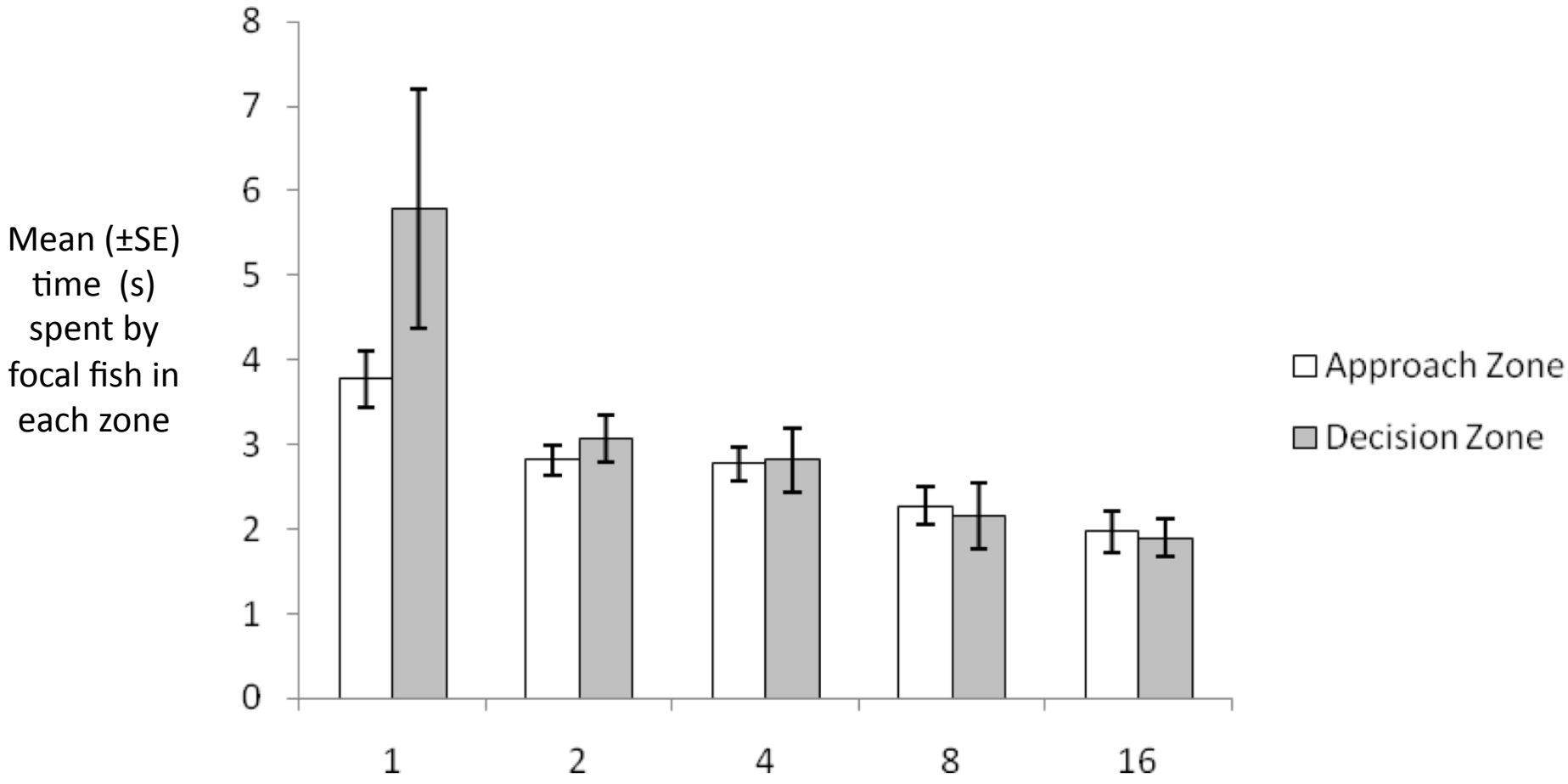
Ward et al. (2011), *Proceedings of the National Academy of Sciences*

Predator avoidance increases with group size



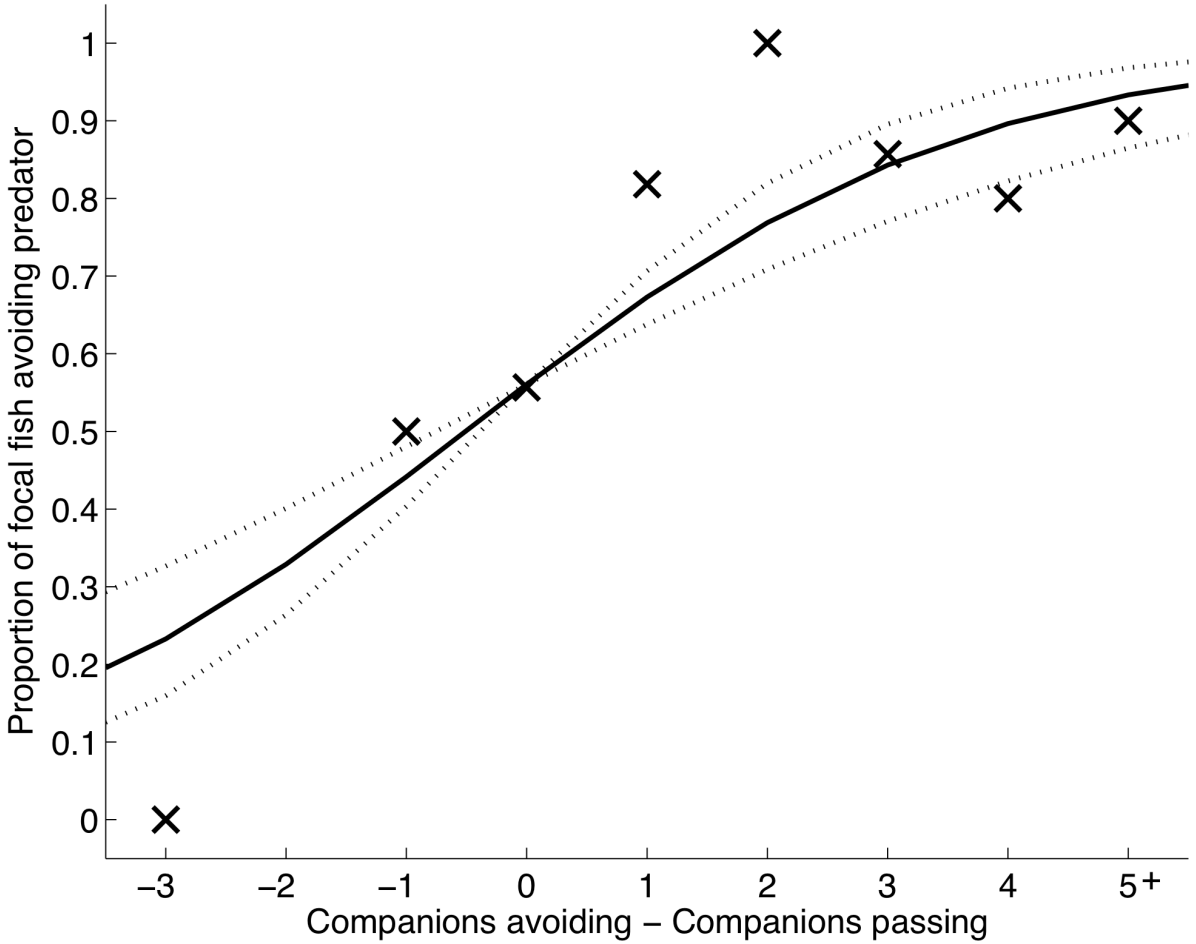
Ward et al. (2011), *Proceedings of the National Academy of Sciences*

Time taken decreases with group size



Ward et al. (2011), *Proceedings of the National Academy of Sciences*

Quorum responses



Ward et al. (2008,2011) *PNAS,* Sumpter et al. (2008) *Current Biology,*
Sumpter & Pratt (2009) *Philosophical Transactions of Royal Society B*

Collective behaviour
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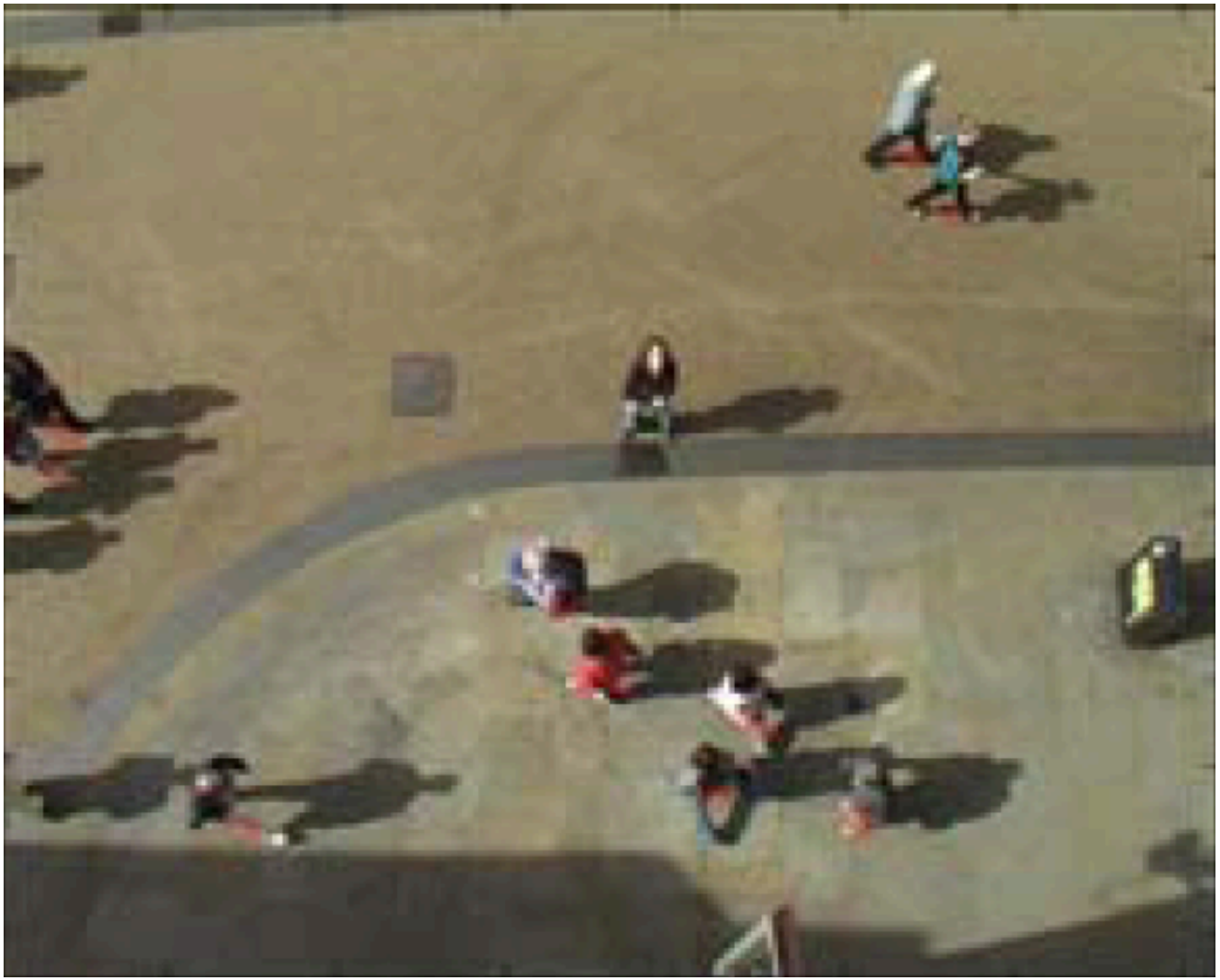
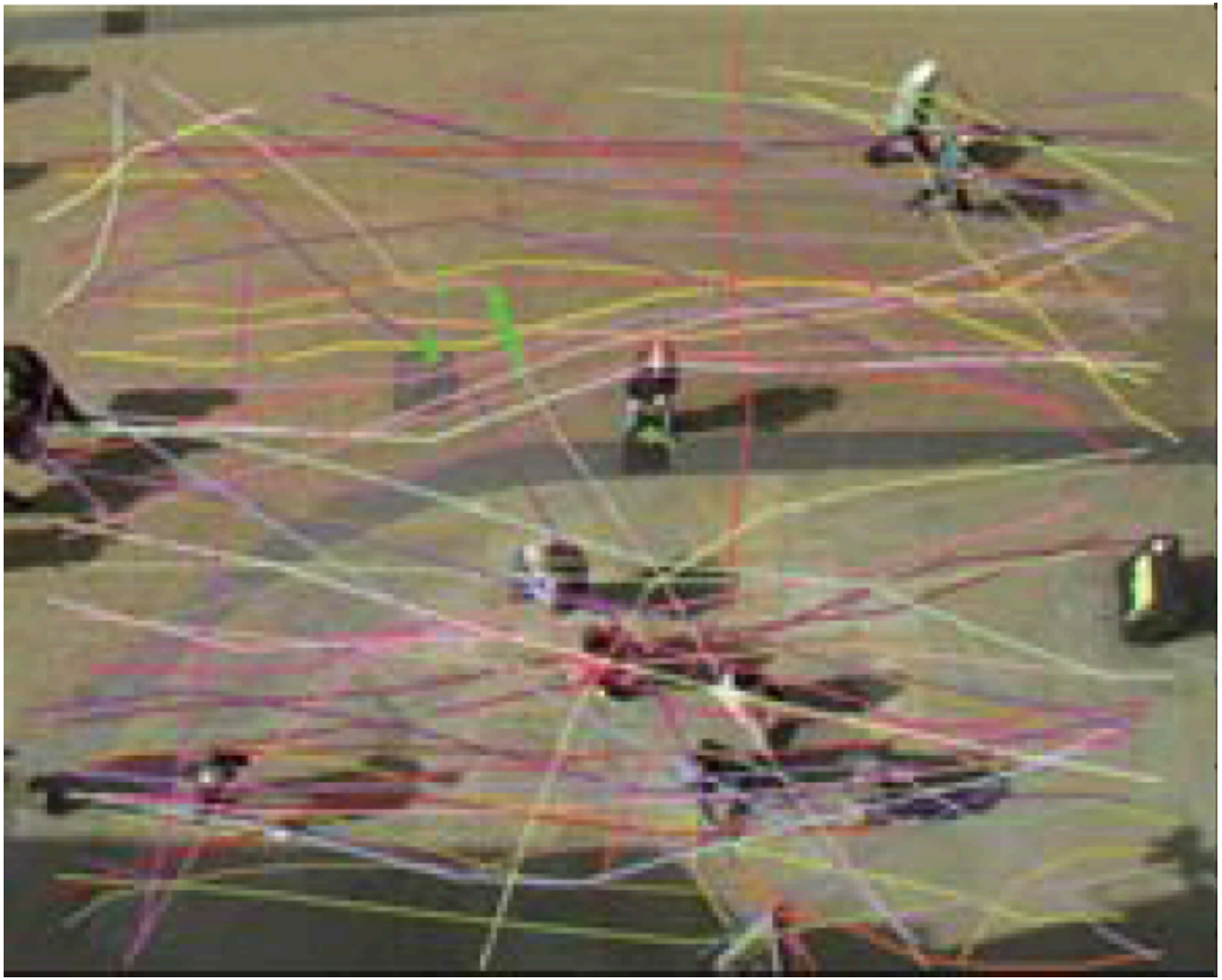
Look up!



Gallup, Hale, Sumpter, Garnier, Krebs, Kacelnik & Couzin, submitted

Look up!



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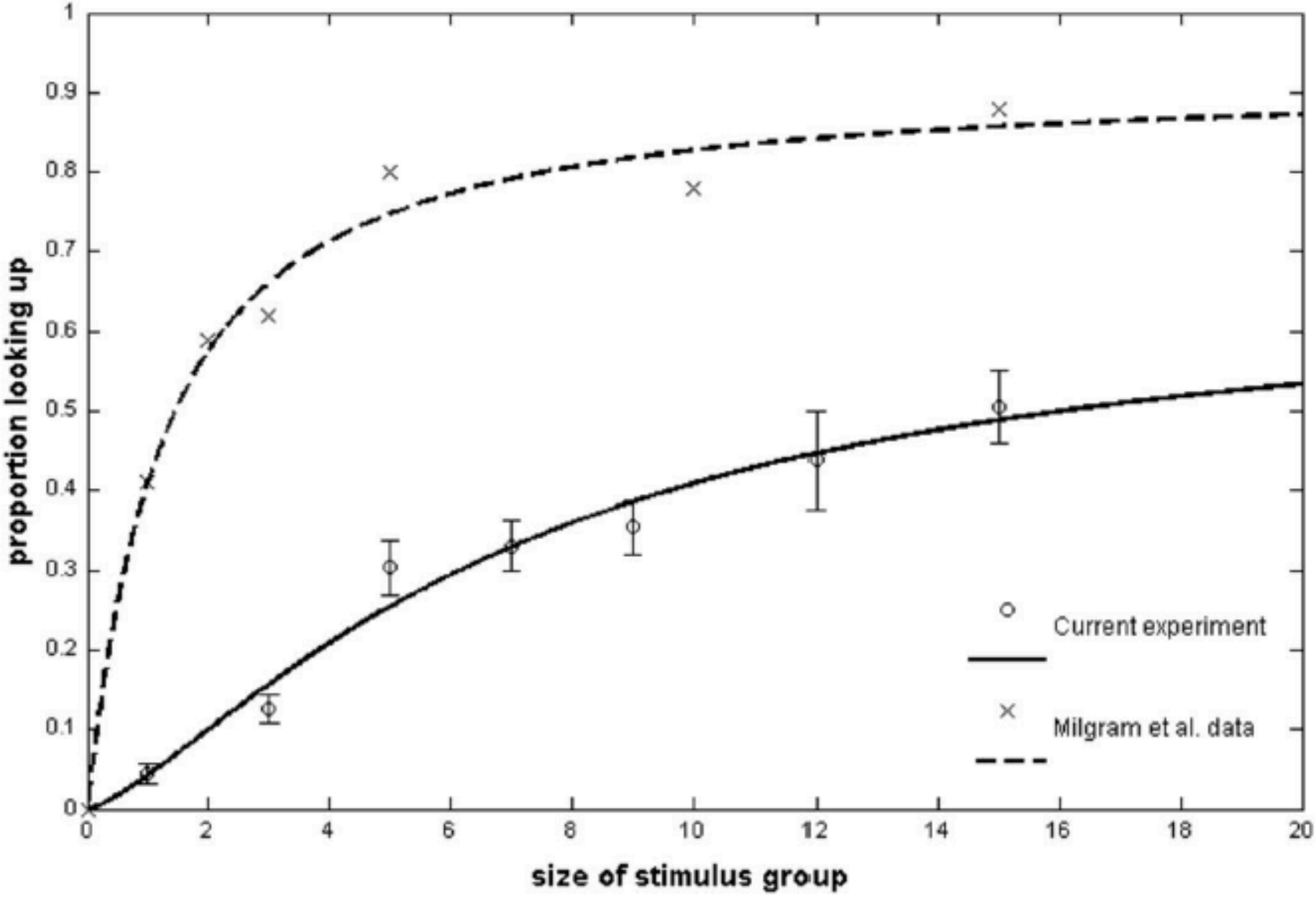

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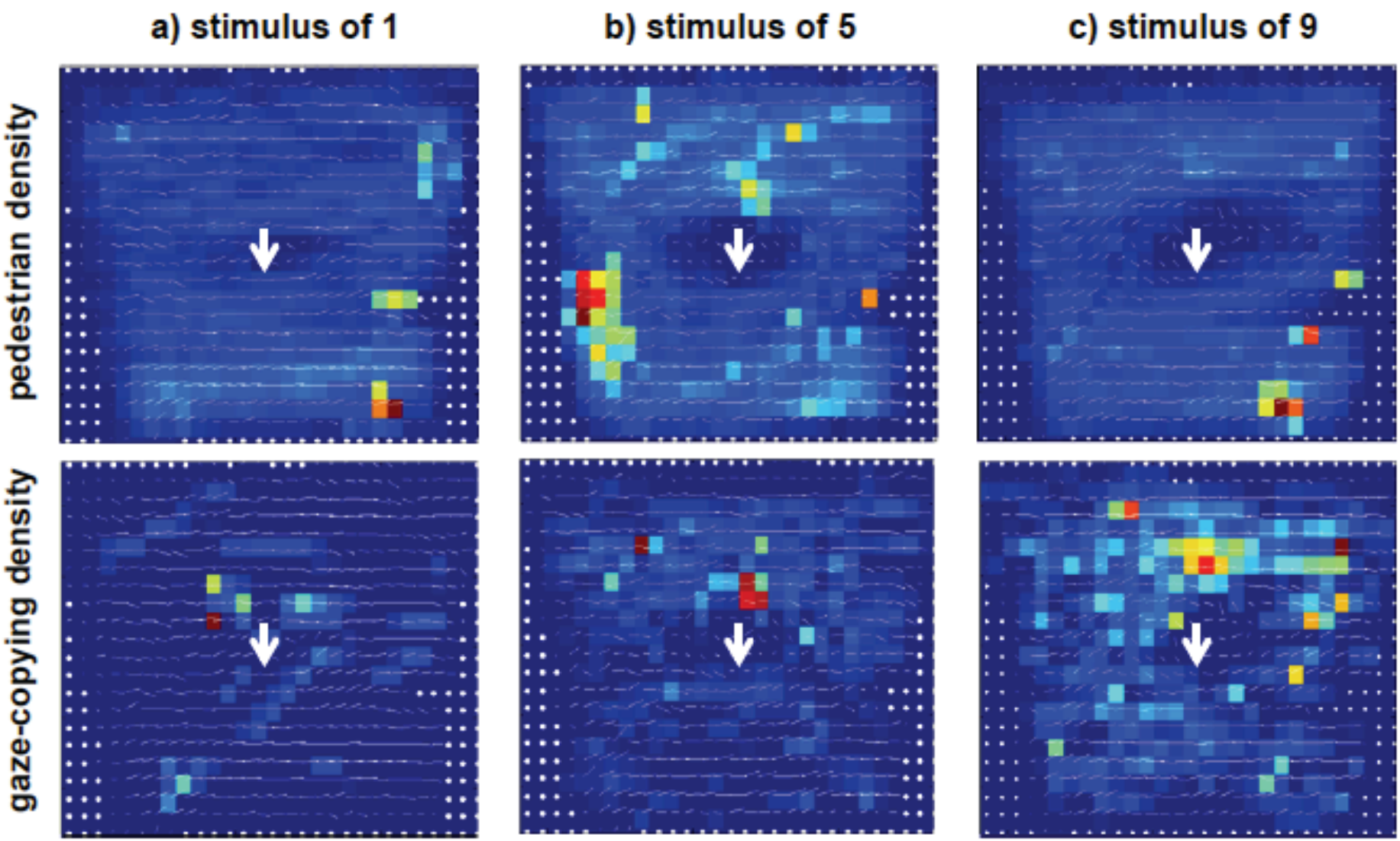

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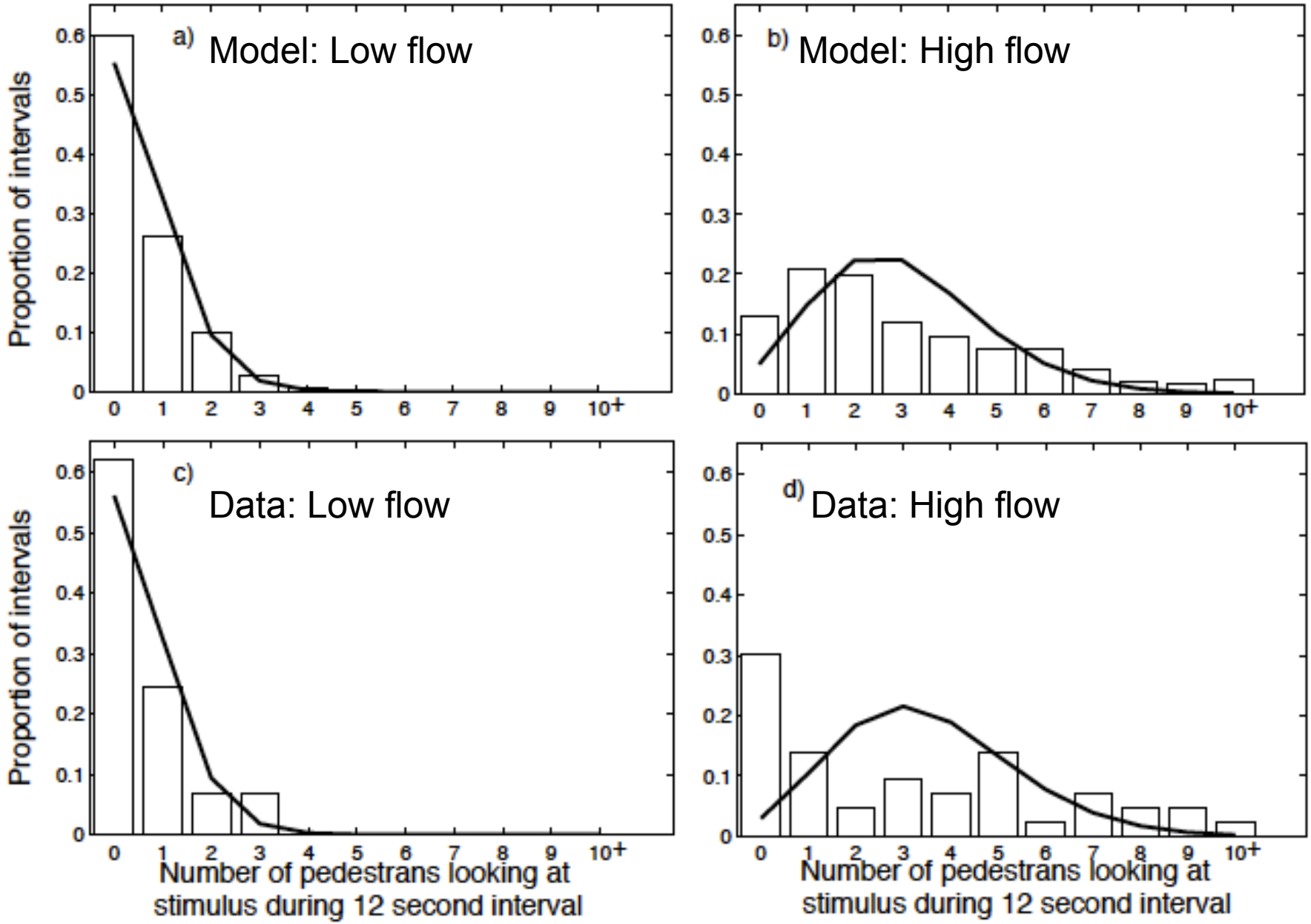
a) Model: Low flow
b) Model: High flow
c) Data: Low flow
d) Data: High flow
Proportion of intervals
Proportion of intervals
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10+
Number of pedestrans looking at stimulus during 12 second interval
Number of pedestrans looking at stimulus during 12 second interval

Collective behaviour
What questions do we ask?

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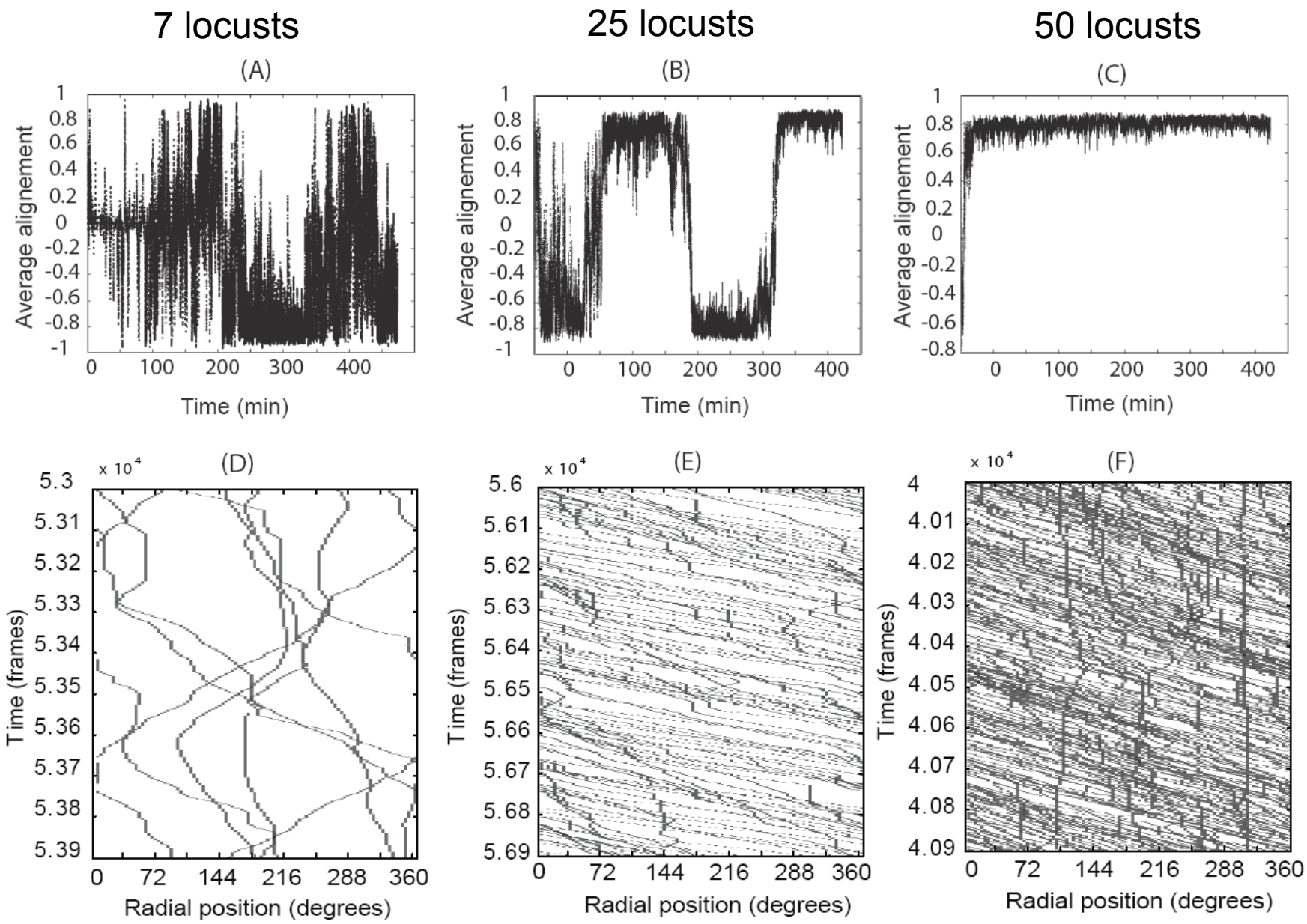
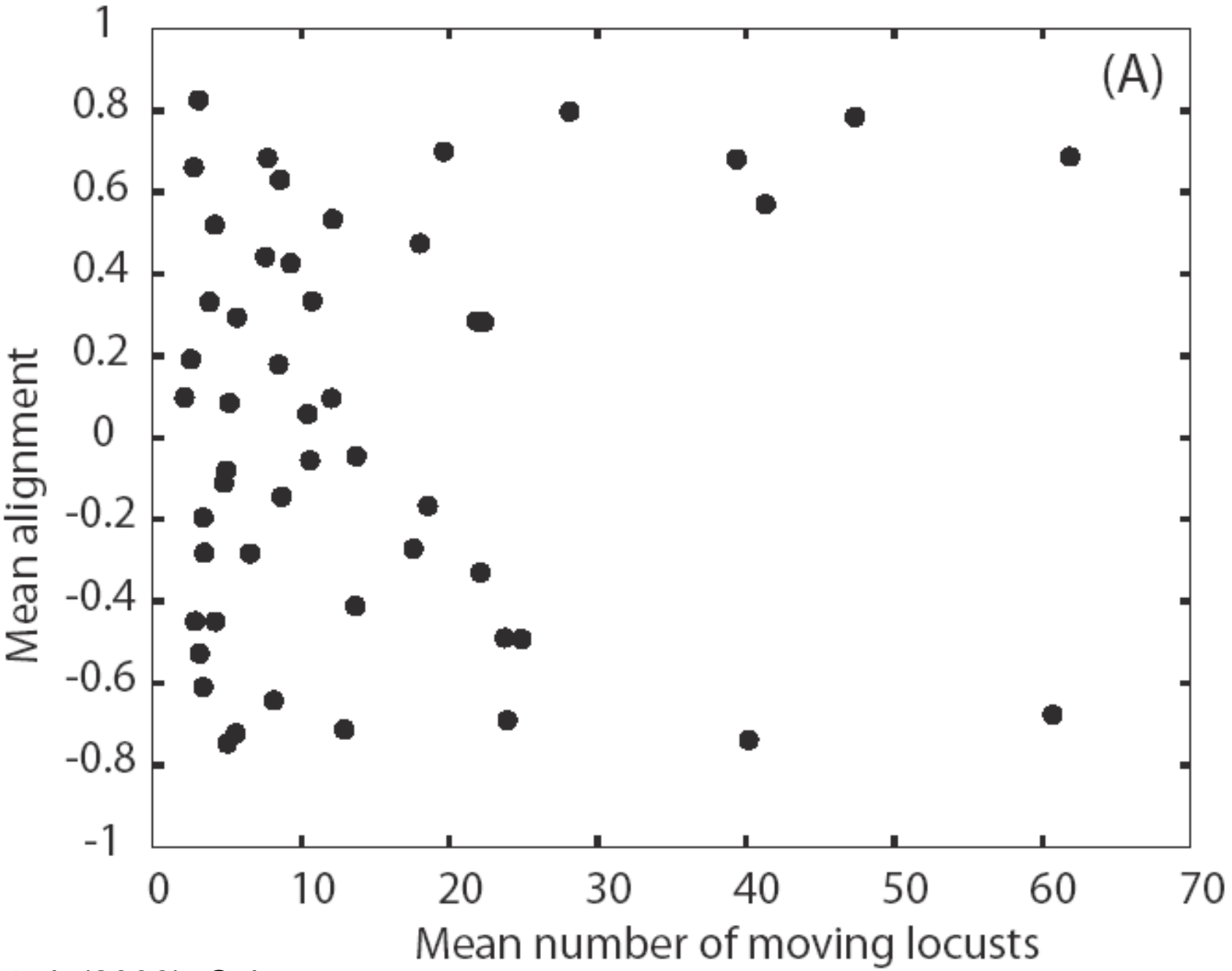
Buhl et al. (2006), *Science*
Yates et al. (2009), *PNAS*



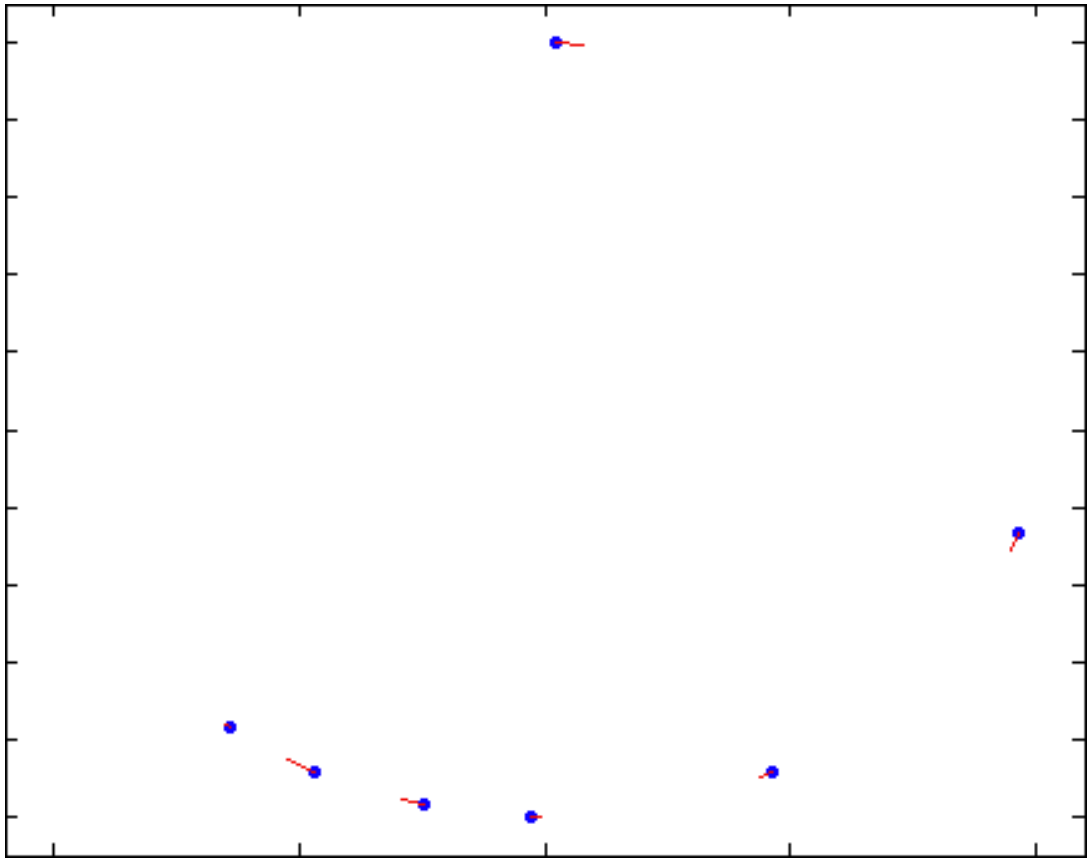
Buhl et al. (2006), *Science*



Buhl et al. (2006), *Science*

1D self-propelled particles

7 particles



Position:

$$x_i(t+1) = x_i(t) + v_0 u_i(t)$$

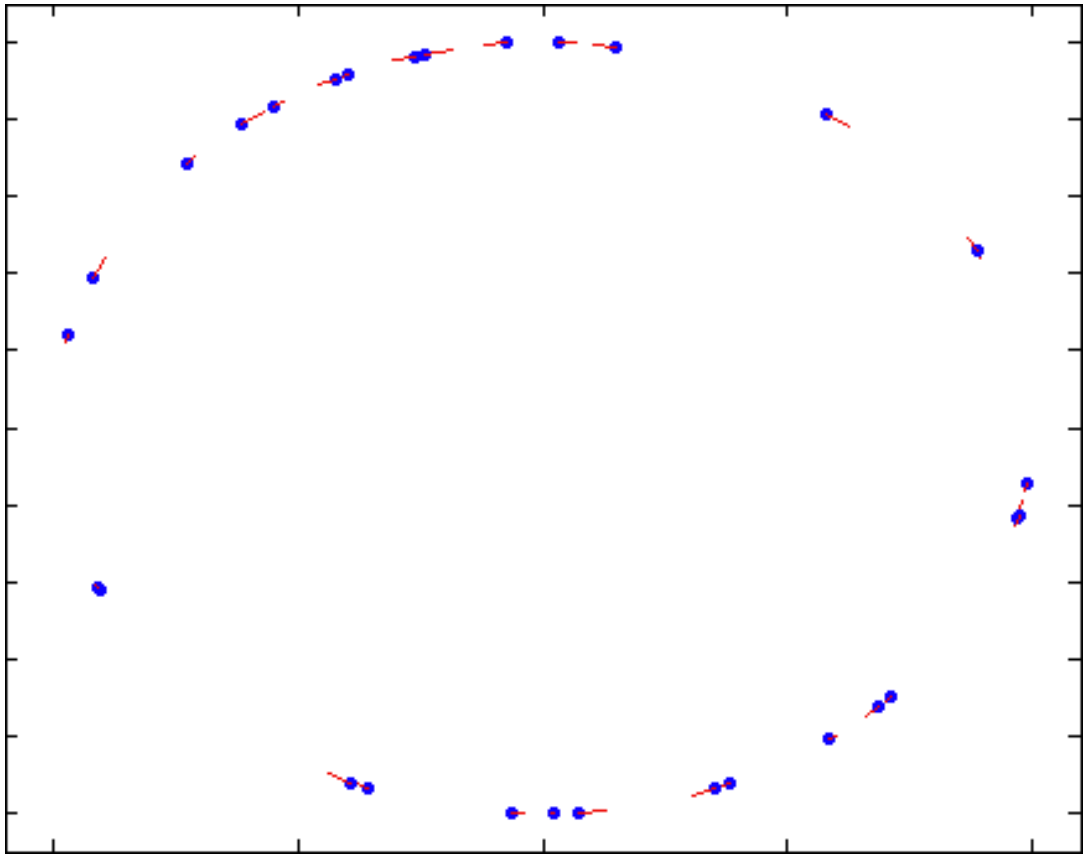
Velocity:

$$u_i(t+1) = \alpha u_i(t) + (1-\alpha) G\left[\left\langle u_j(t)\right\rangle_{|i-j|<r}\right] + \xi_i,$$

Buhl et al. (2006), *Science*

1D self-propelled particles

30 particles



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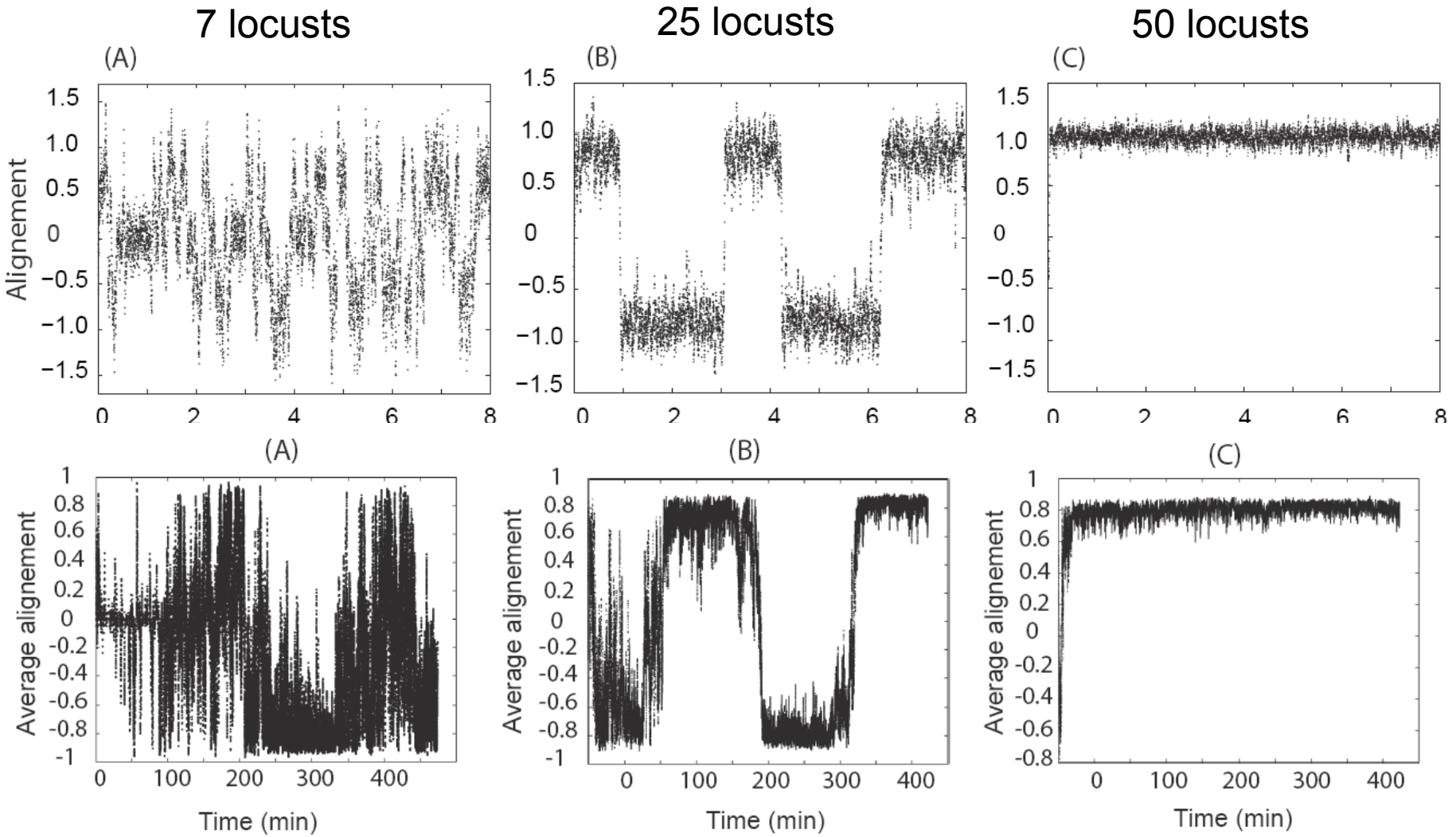
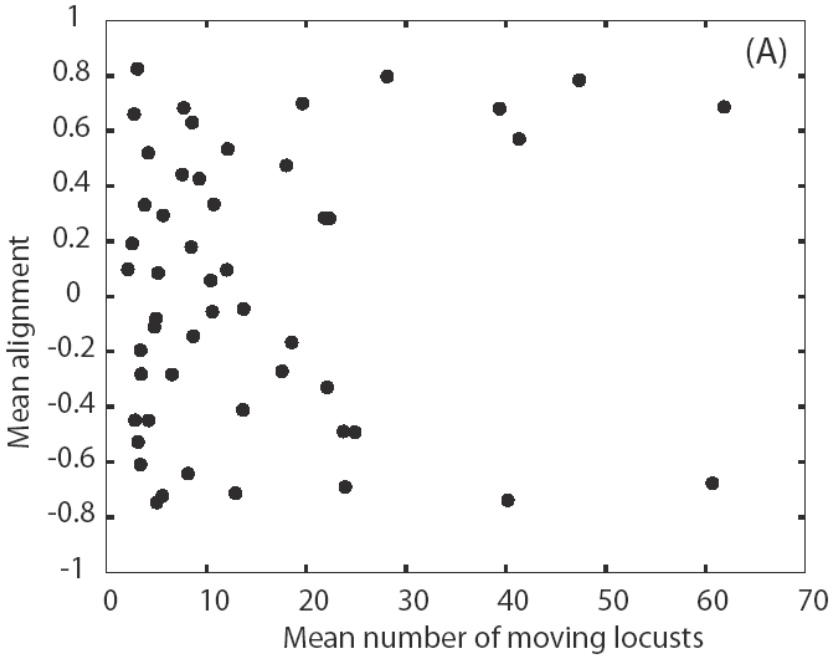
Buhl et al. (2006), *Science*

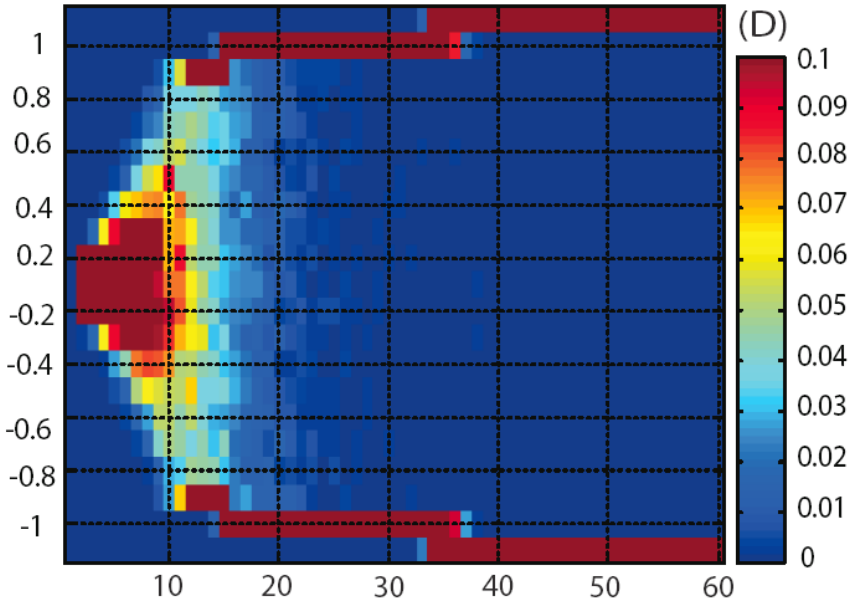
Model vs Data



Buhl et al. (2006), *Science*

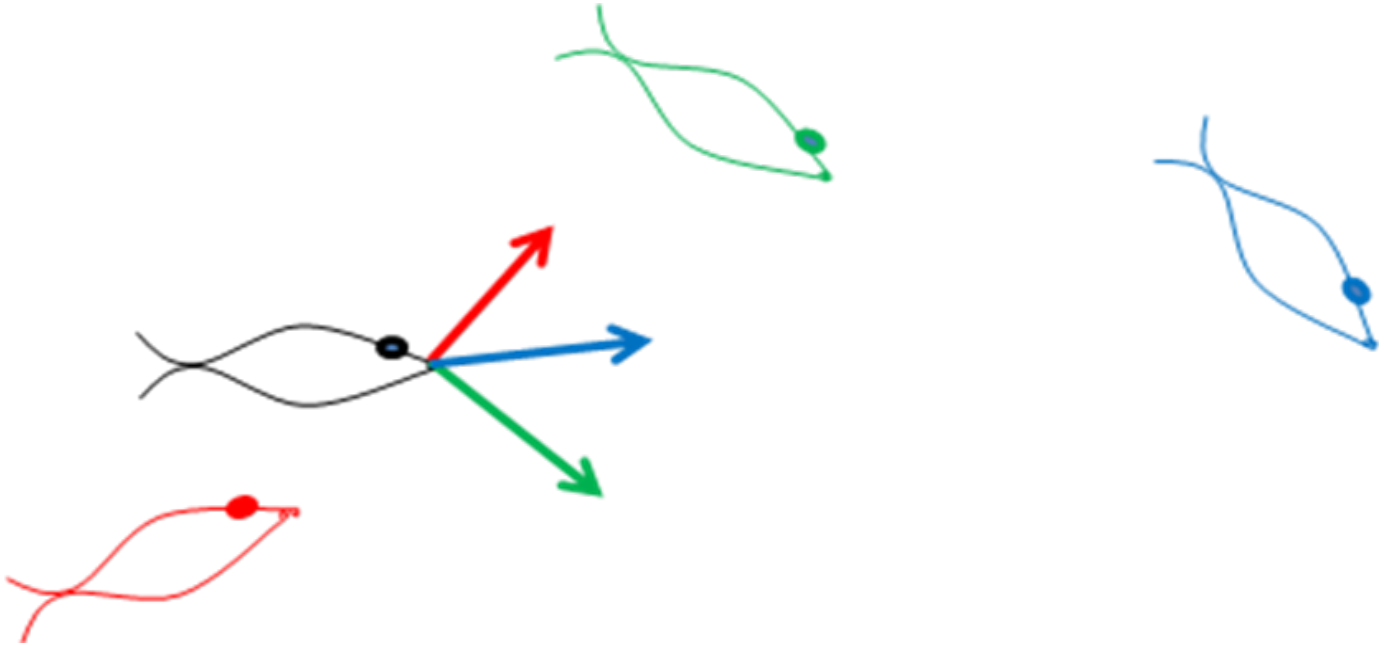
Model vs Data





Buhl et al. (2006), *Science*

Self-propelled particle models



future position current position current velocity

$$\underline{x}_i(t+1) = \underline{x}_i(t) + v_0 \underline{u}_i(t+1)$$

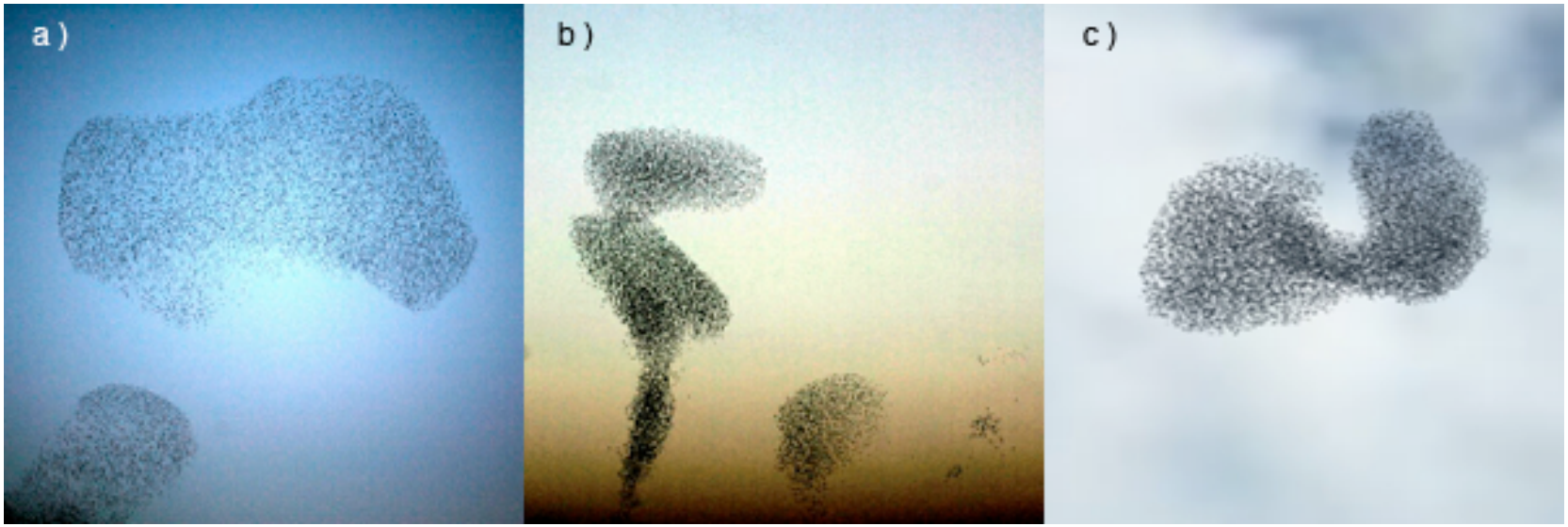
$$\underline{u}_i(t+1) = f(\underline{u}_i(t), \{(\underline{x}_j(t), \underline{u}_j(t)) : j \text{ is a neighbour}\}, \underline{e})$$

future velocity

current velocity

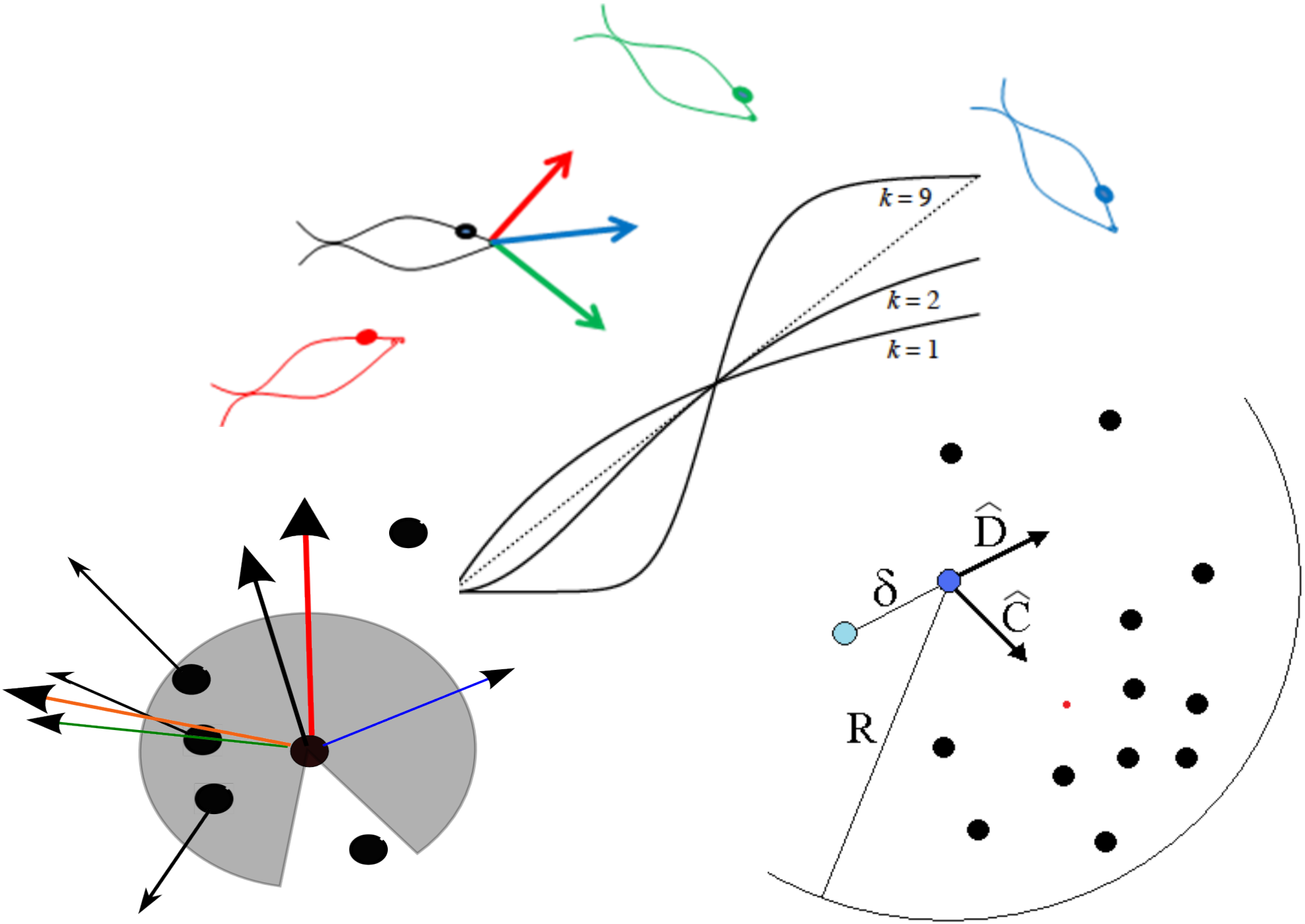
position and velocity of neighbours

stochastic effect



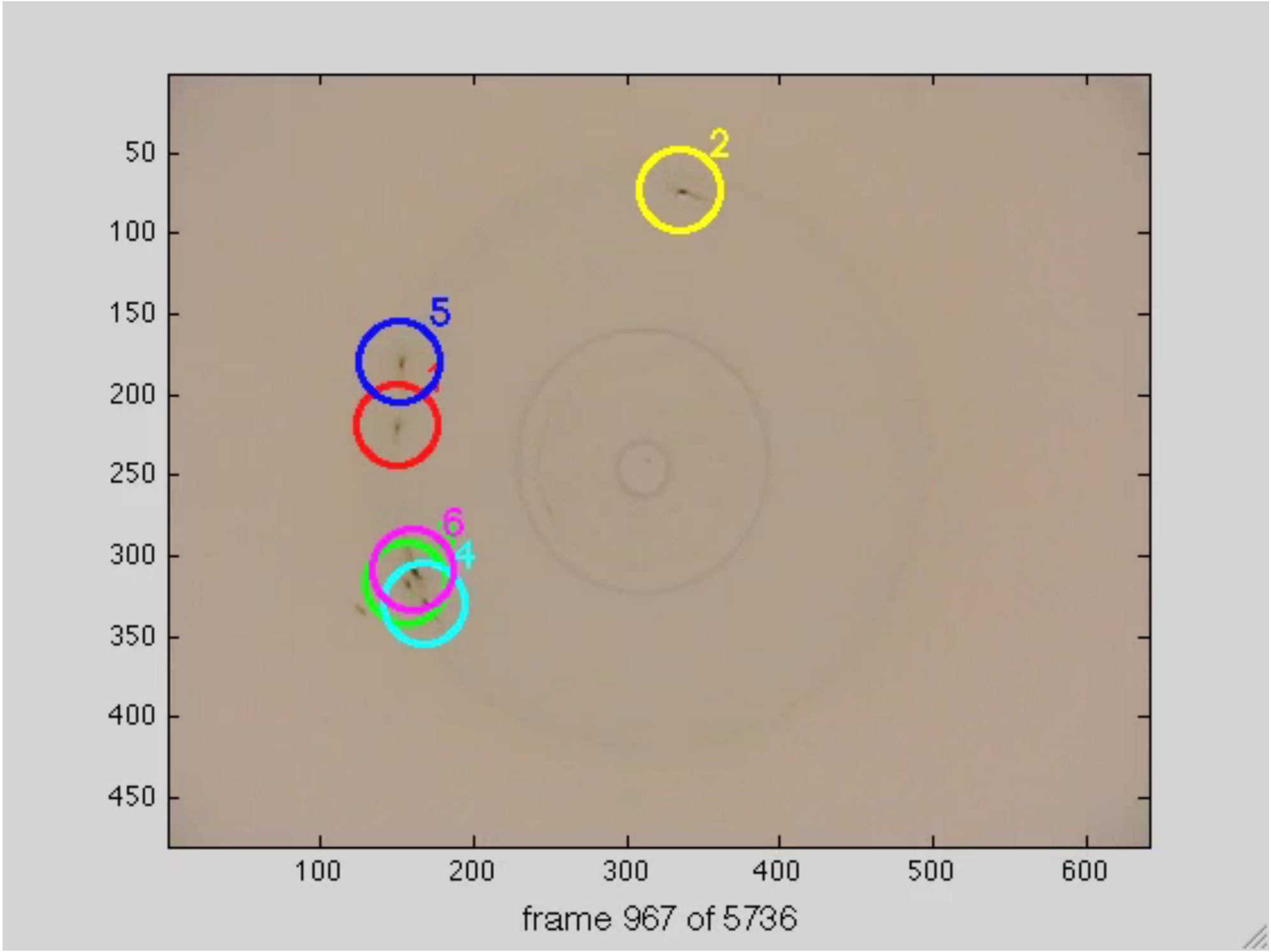
Ginelli, F. & Chaté, H., *Phys. Rev. Lett.*, 105 168103 (2010).

Hemelrijk, C. K. & Hildenbrandt, H. *PLoS One* 168103 (2010).


k = 9
k = 2
k = 1
δ
D̂
Ĉ
R

Too many models, not enough data

- Thousands of (possibly 10,000) papers on SPP models. Many of which generate realisitic looking schooling behaviour.
- Some ‘universal’ properties established of these models (Vicsek & Zafiris, 2010).
- Few studies which identify the actual rules of interaction.


50
100
150
200
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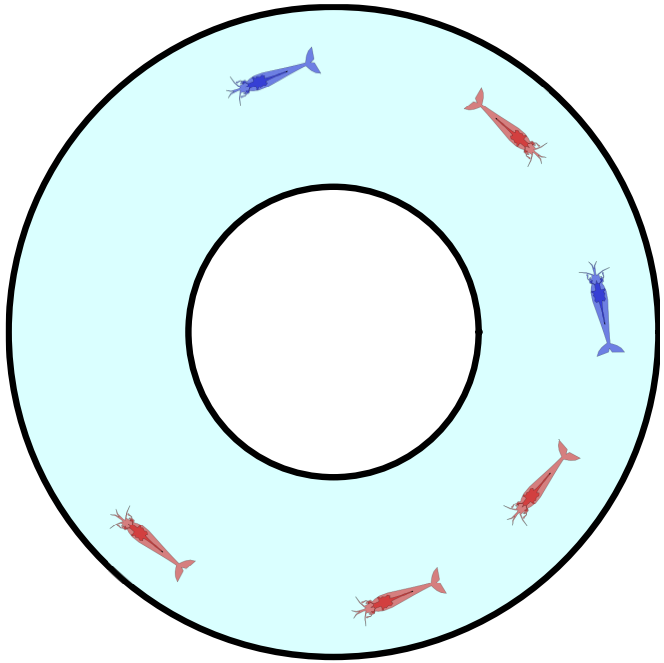
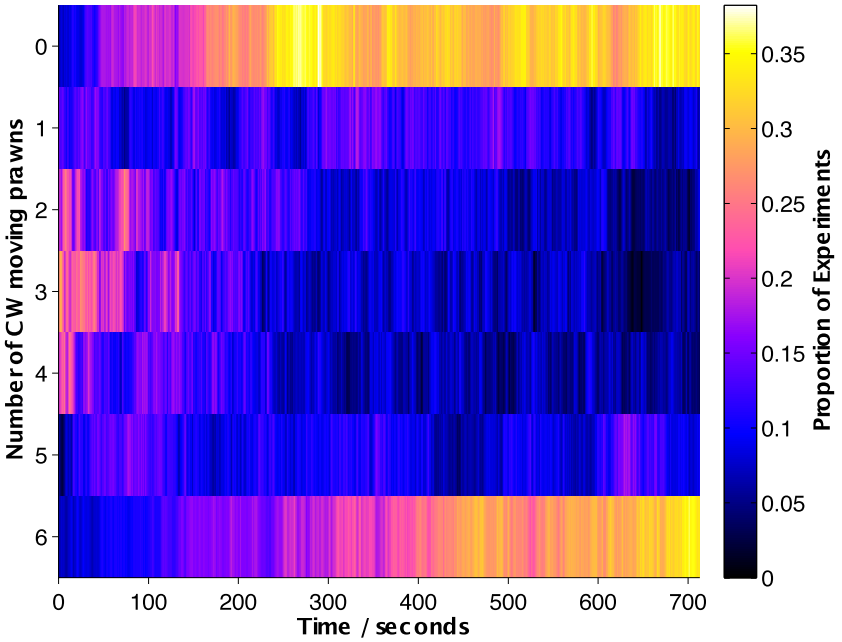
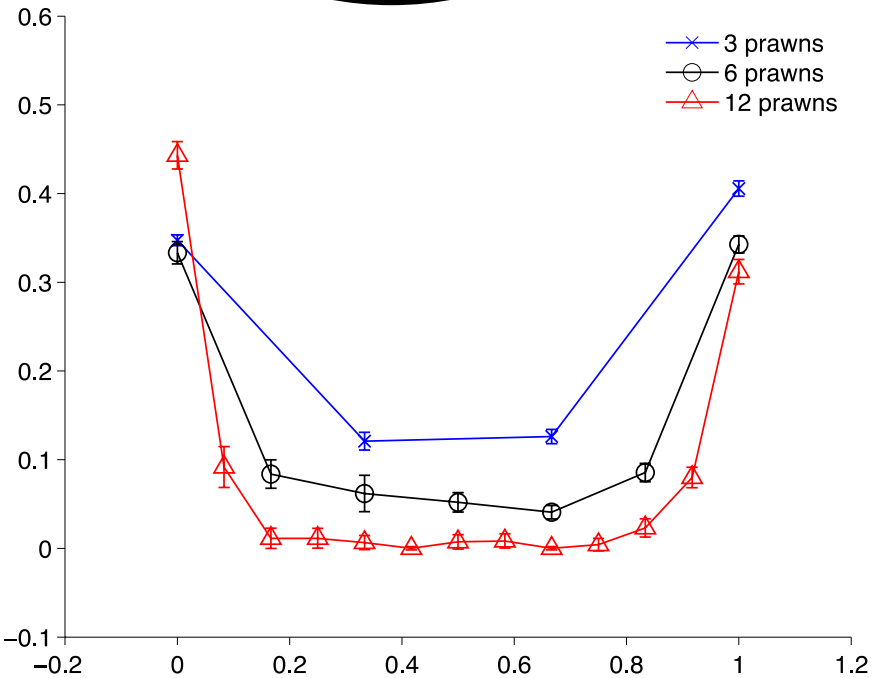
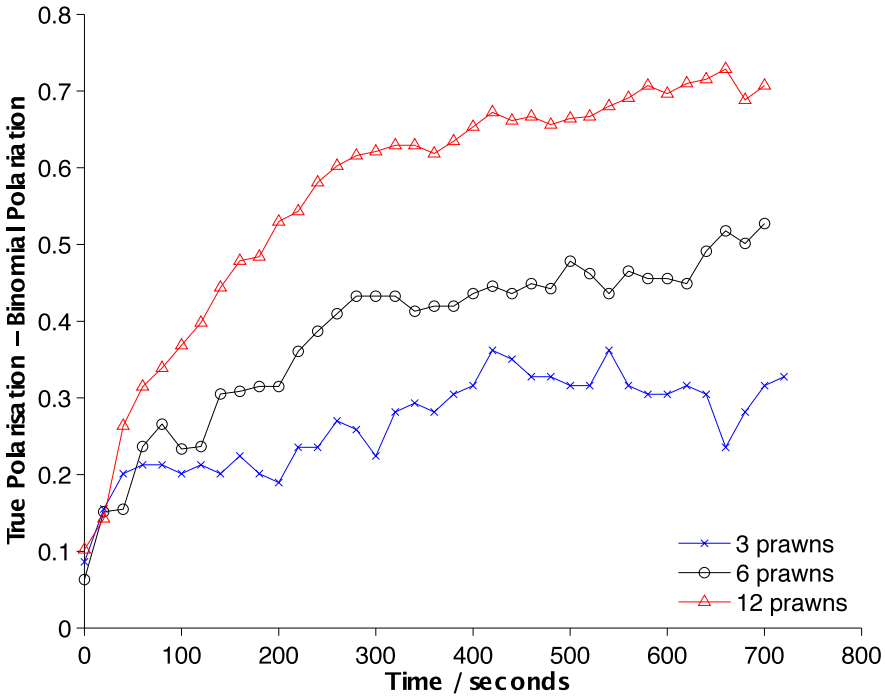
2
5
1
6
4
frame 967 of 5736







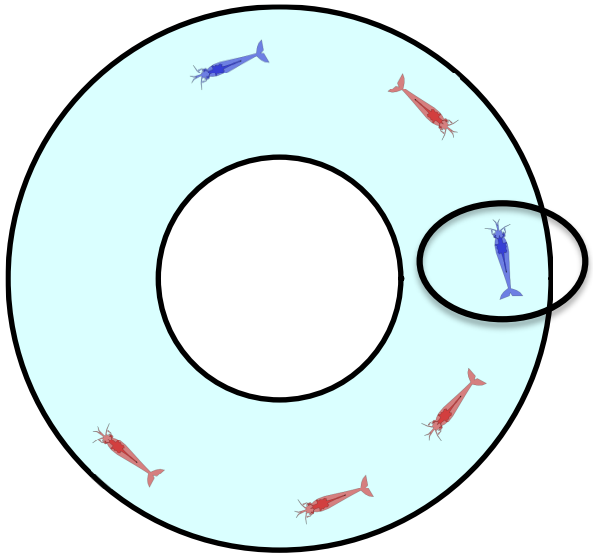


Mann et al. (submitted)

$$P(\text{direction change} \mid s) = 1/(1+\exp(-s))$$

Independent (N) $s = q$

Global Interaction (MF) $s = q + \lambda_- N_-$



Nearest Neighbours (T) $s = q + \lambda_- N_{\mathcal{K}-}$

$\mathcal{K}$ set of nearest-neighbours

Interaction Radius (S1-4) $s = q + \lambda_- N_{\mathcal{R}-} + \lambda_+ N_{\mathcal{R}+}$

$\mathcal{R}$ zone-of-interaction,

Mann et al. *PLoS Computational Biology* (in press)

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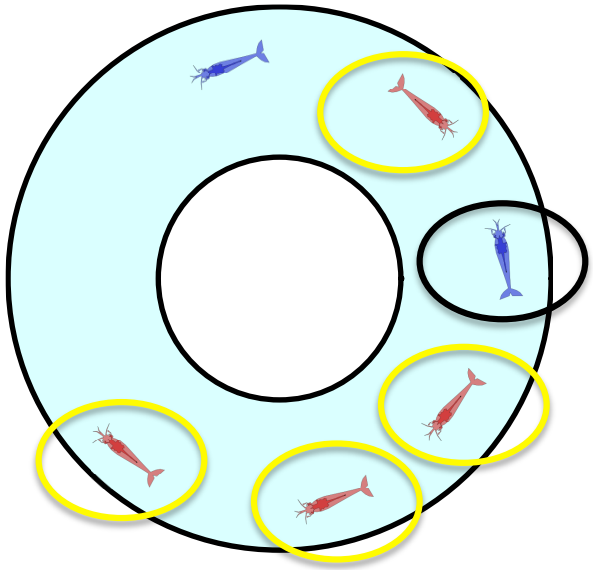

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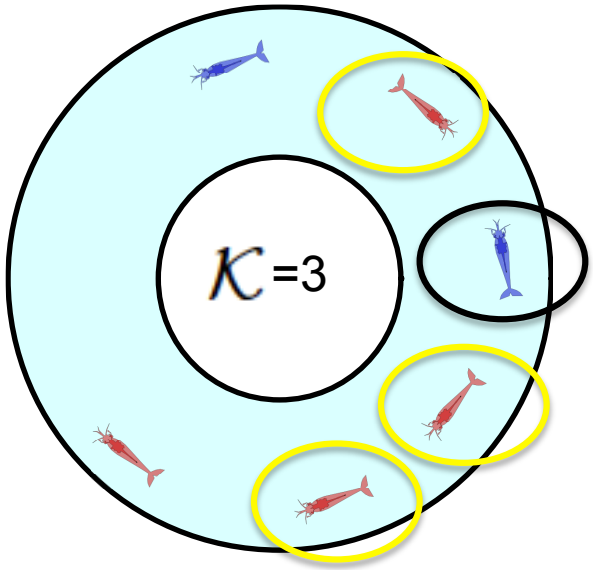

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Mann et al. *PLoS Computational Biology* (in press)

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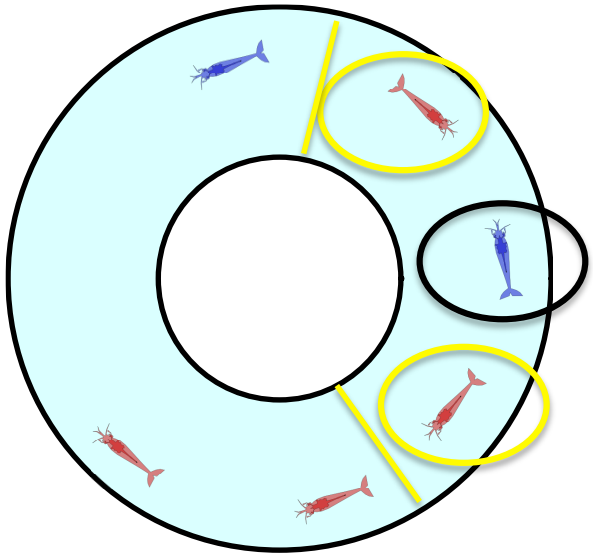

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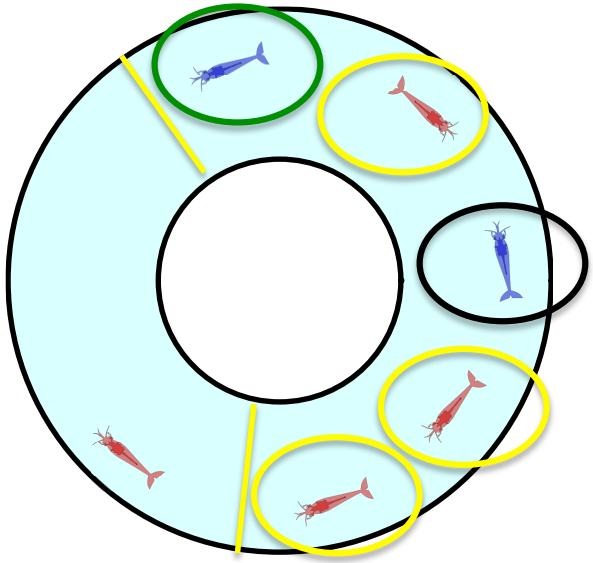

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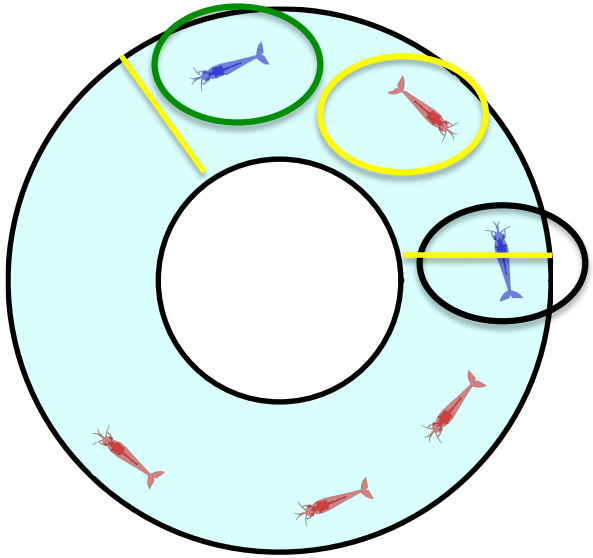

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zone-of-interaction, $\mathcal{R}$

Mann et al. *PLoS Computational Biology* (in press)

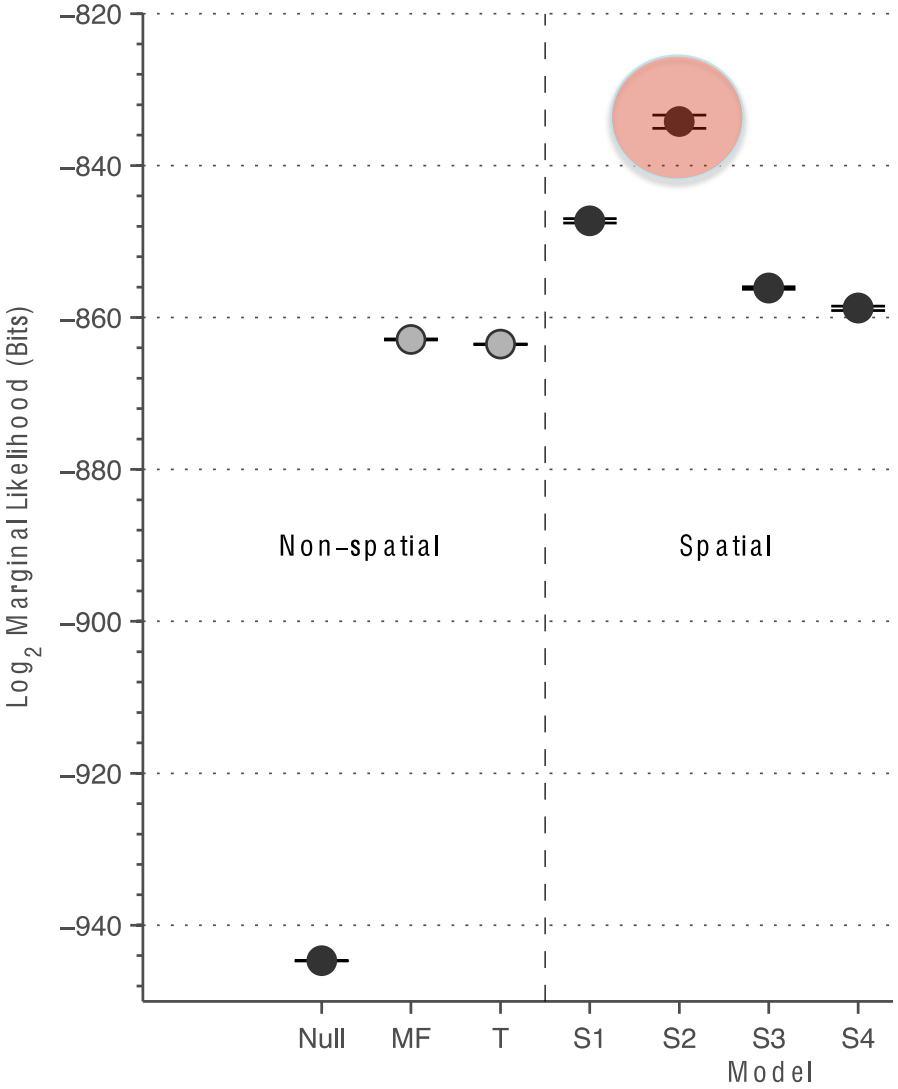
$$P(D|M) = \int P(D|\phi, M)P(\phi)d\phi$$

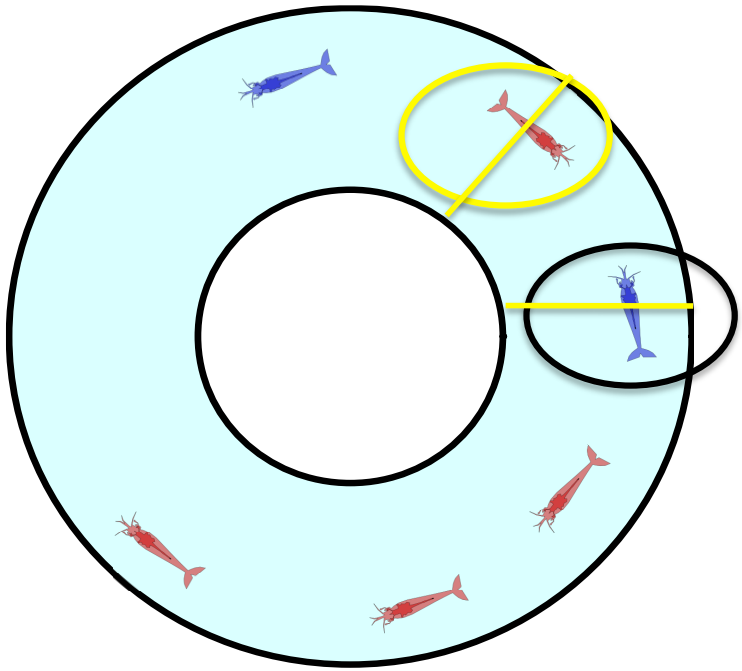
Bayes factor test

$$\mathrm{BF} = \frac{P(D|M_1)}{P(D|M_2)}$$

Mann et al. *PLoS Computational Biology* (in press)

Fine-scale model selection



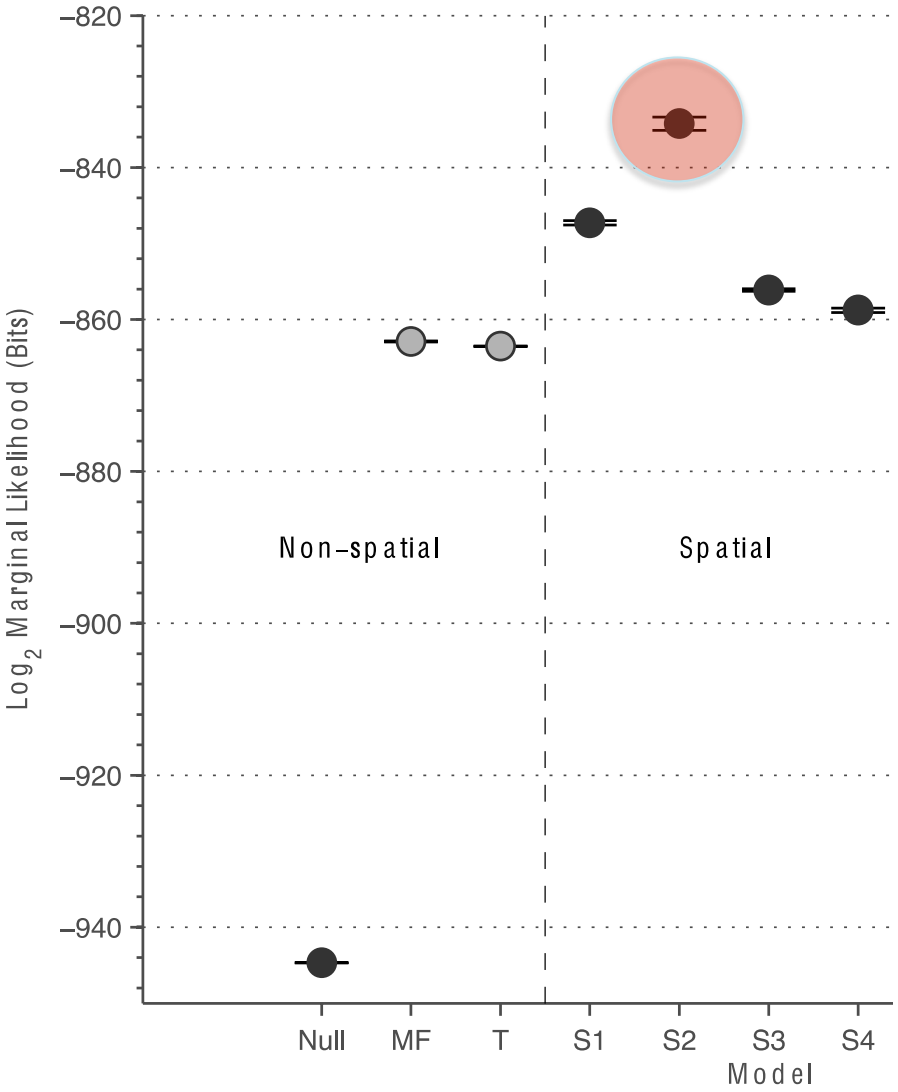


Forward interaction with those moving in opposite direction.

Interaction radius equal to half a prawn body length.

Mann et al. *PLoS Computational Biology* (in press)

Fine-scale model selection

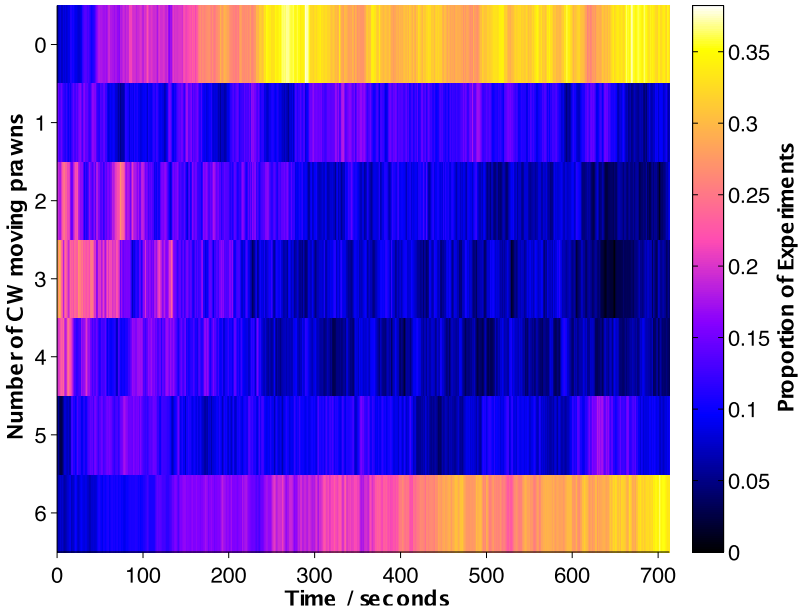


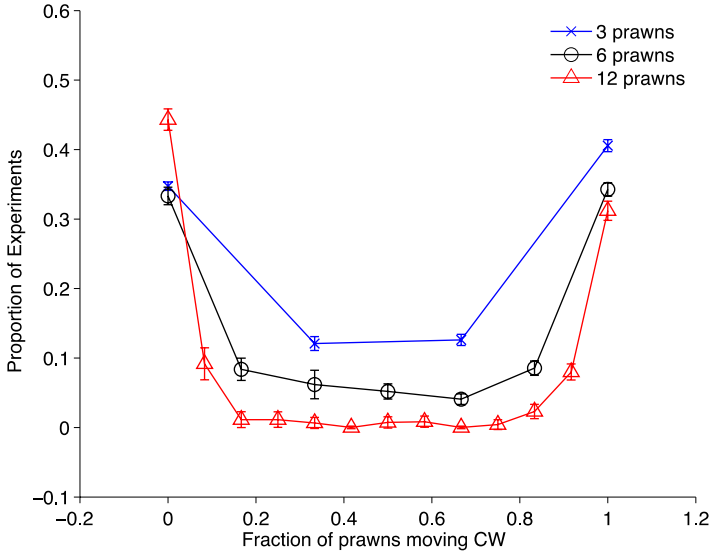
. . . ?

Mann et al. *PLoS Computational Biology* (in press)

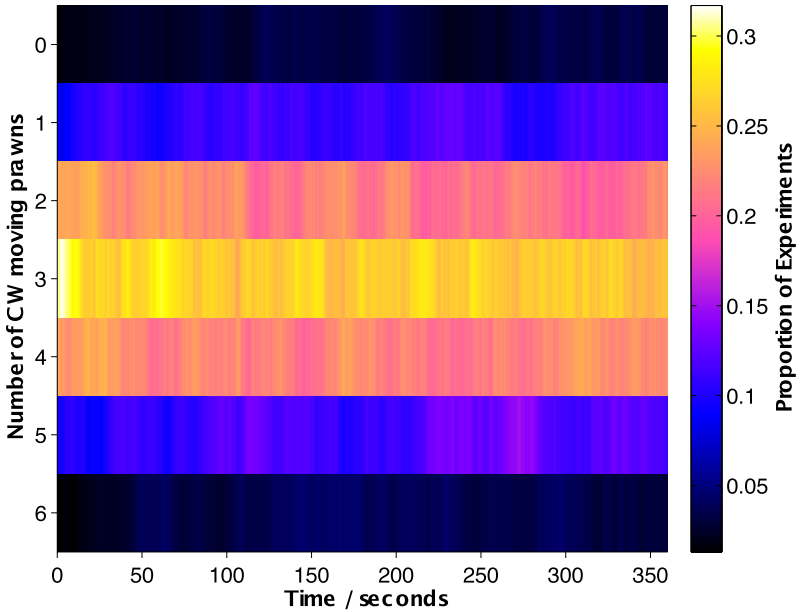
Global-scale fit

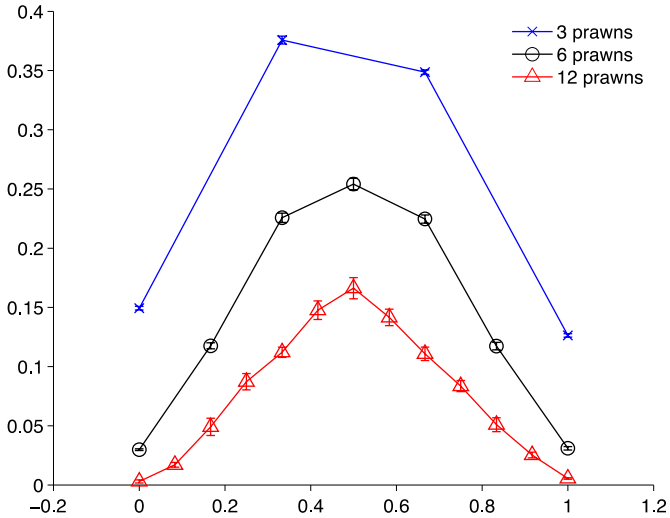
Data





Model

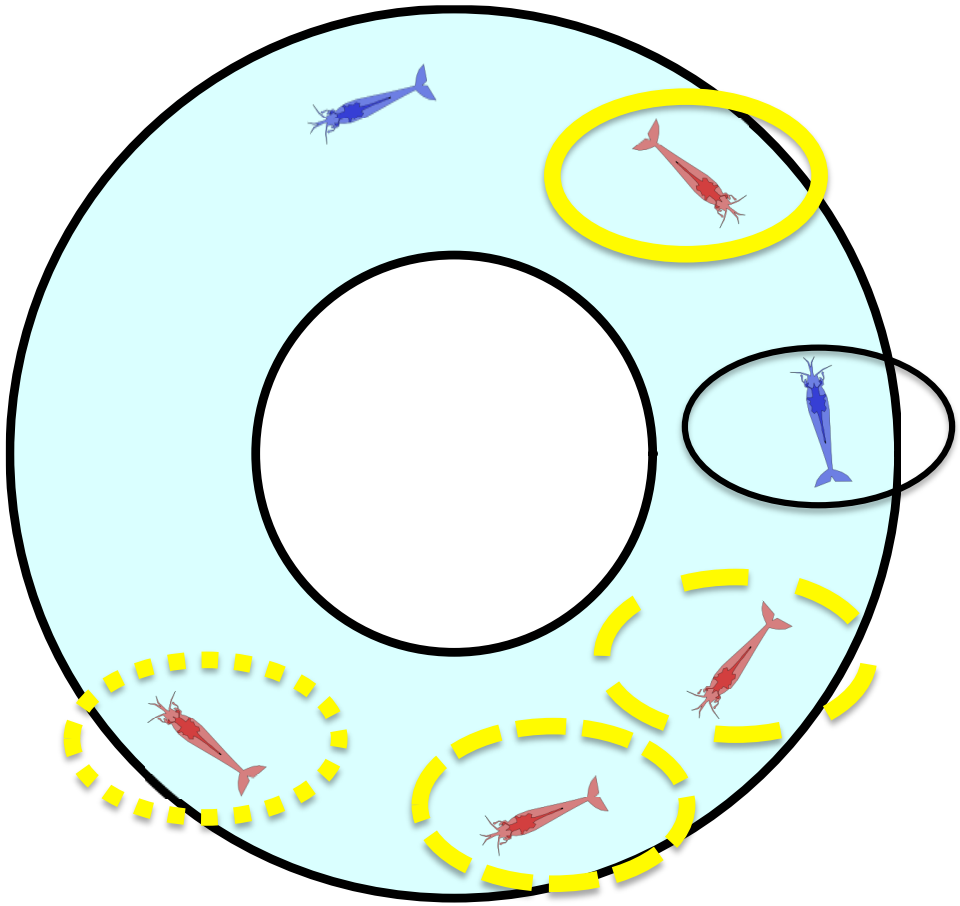




Turning example


INSTANT
RE PLAY

$$P(\text{direction change} \mid s) = 1/(1+\exp(-s))$$

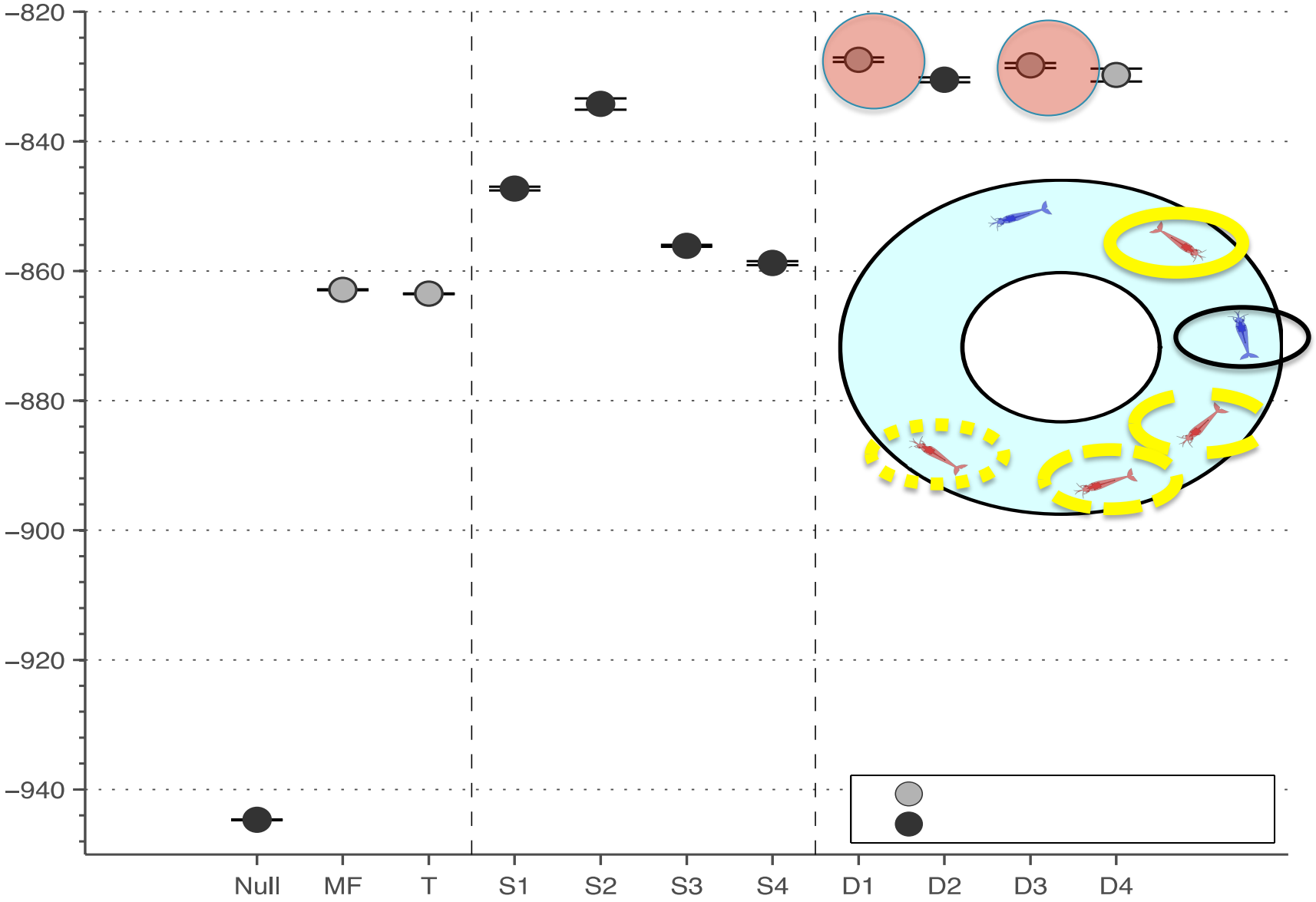


Interaction Radius with Memory (D1-4)

$$s_t = ds_{t-1} + (1-d)[q + \lambda_- N_{\mathcal{R}-}^{t-1} + \lambda_+ N_{\mathcal{R}+}^{t-1}] + \lambda_- N_{\mathcal{R}-}^{t} + \lambda_+ N_{\mathcal{R}+}^{t}$$

Mann et al. *PLoS Computational Biology* (in press)

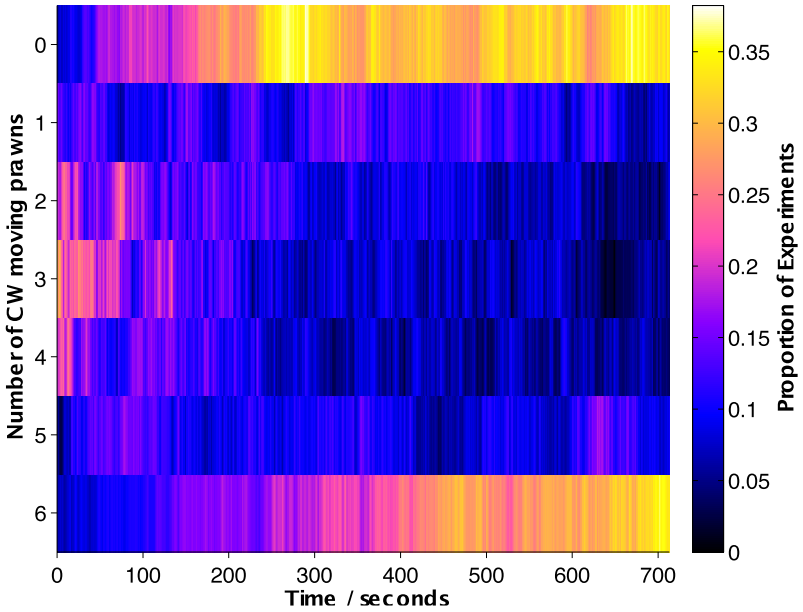
Fine-scale model selection

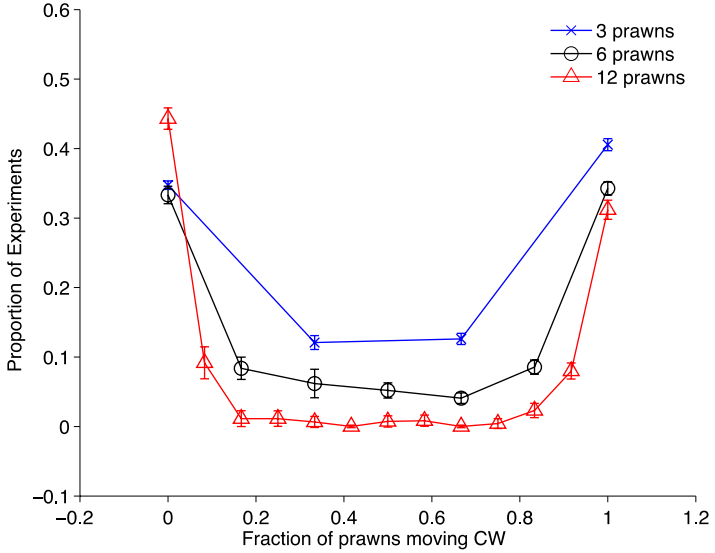


Mann et al. *PLoS Computational Biology* (in press)

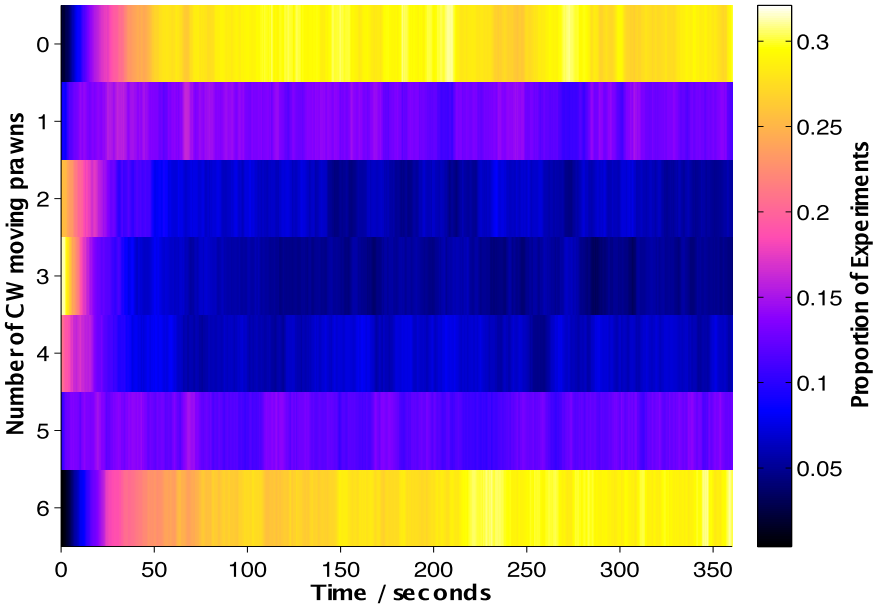
Global-scale fit

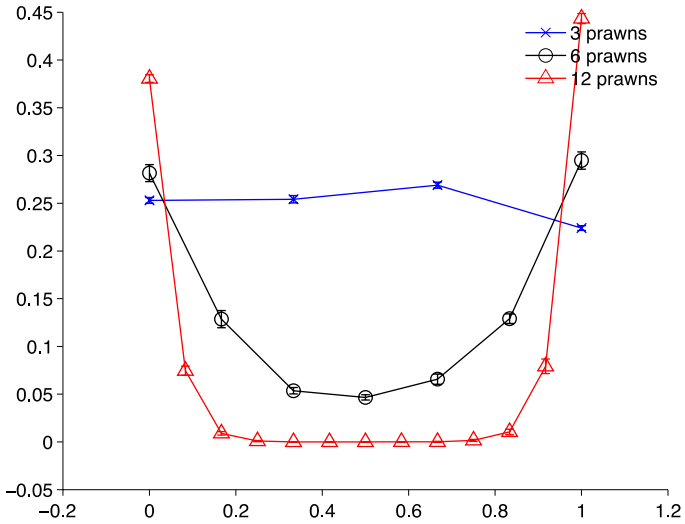
Data

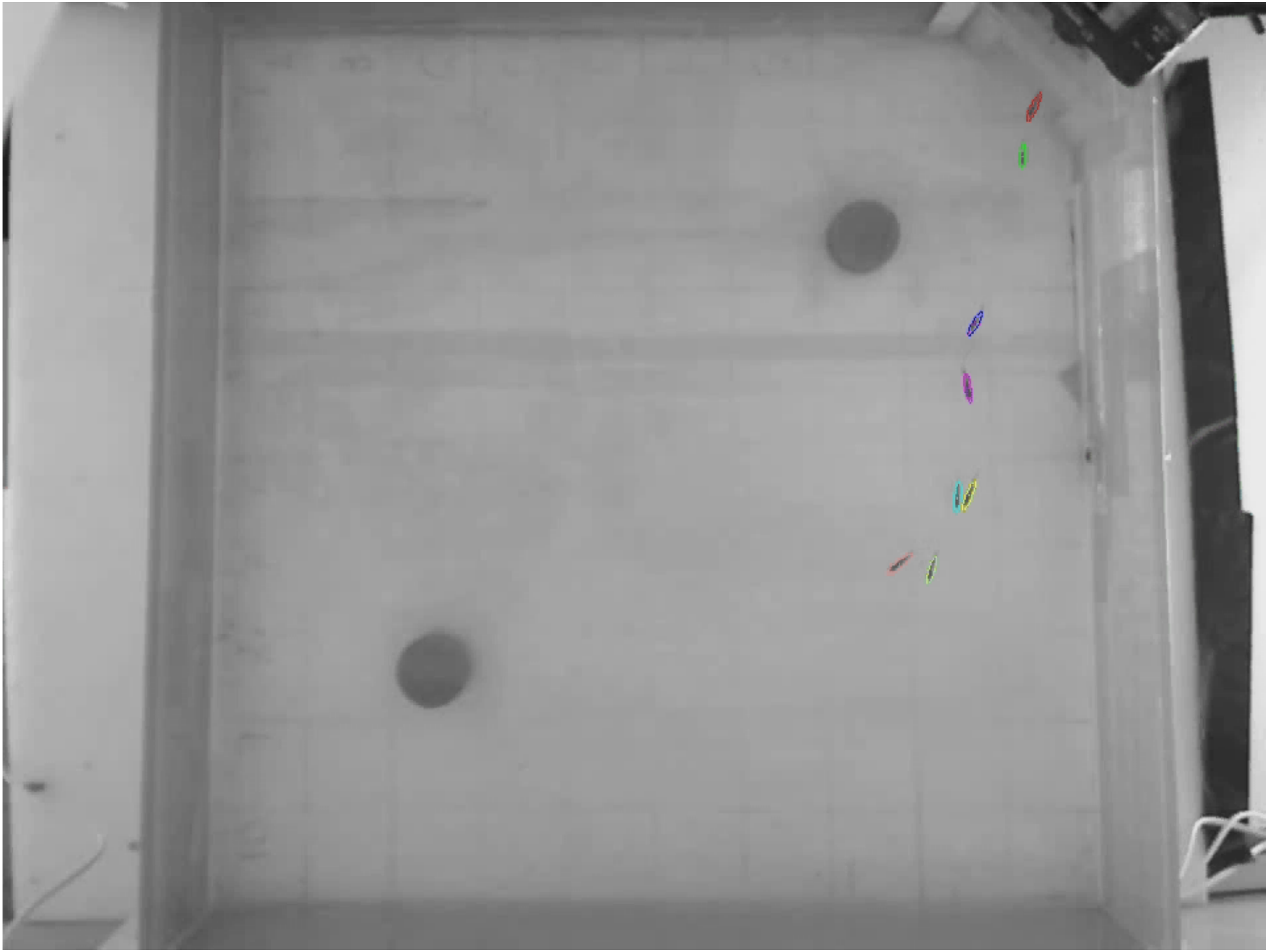


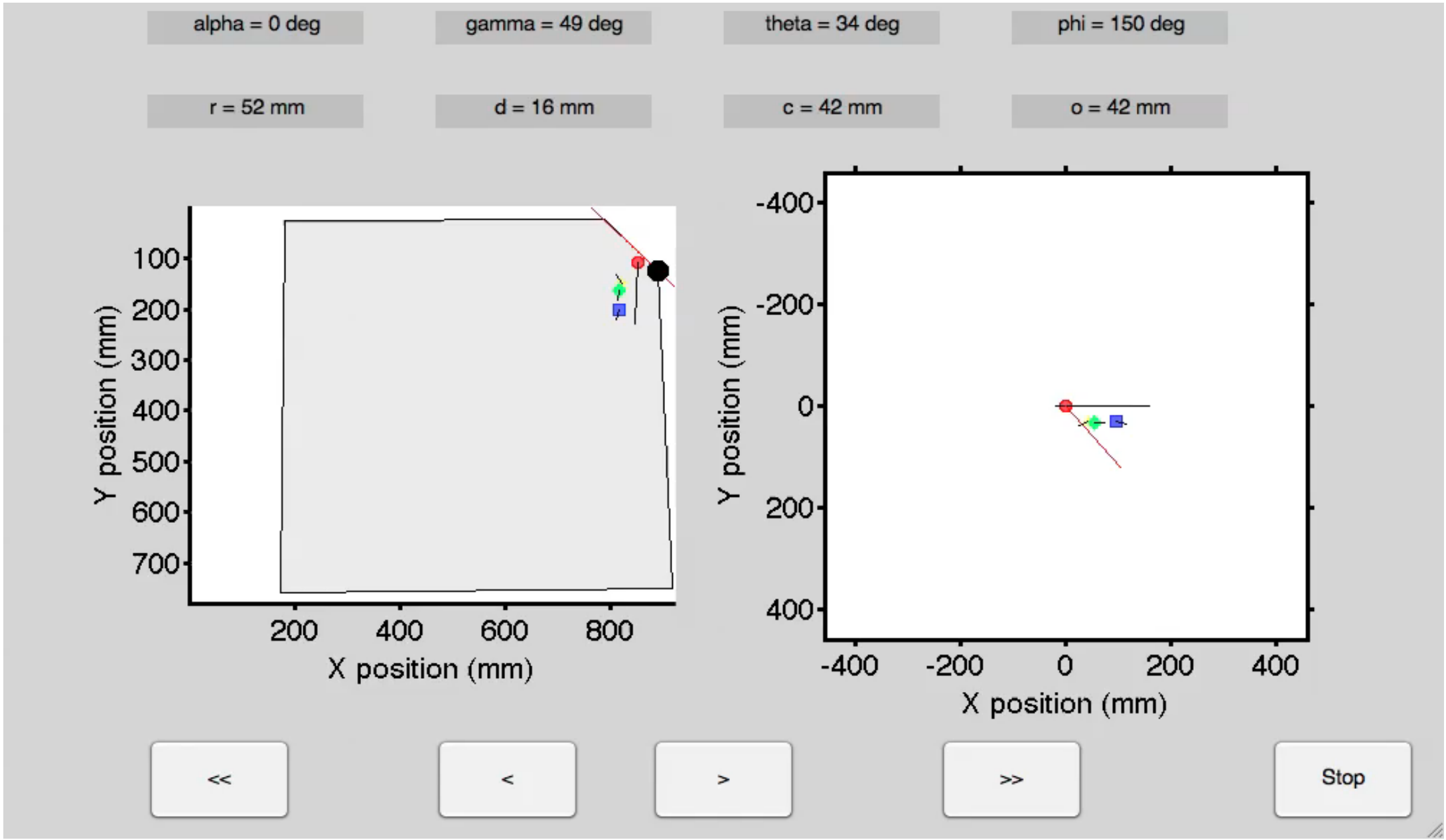


Model D3



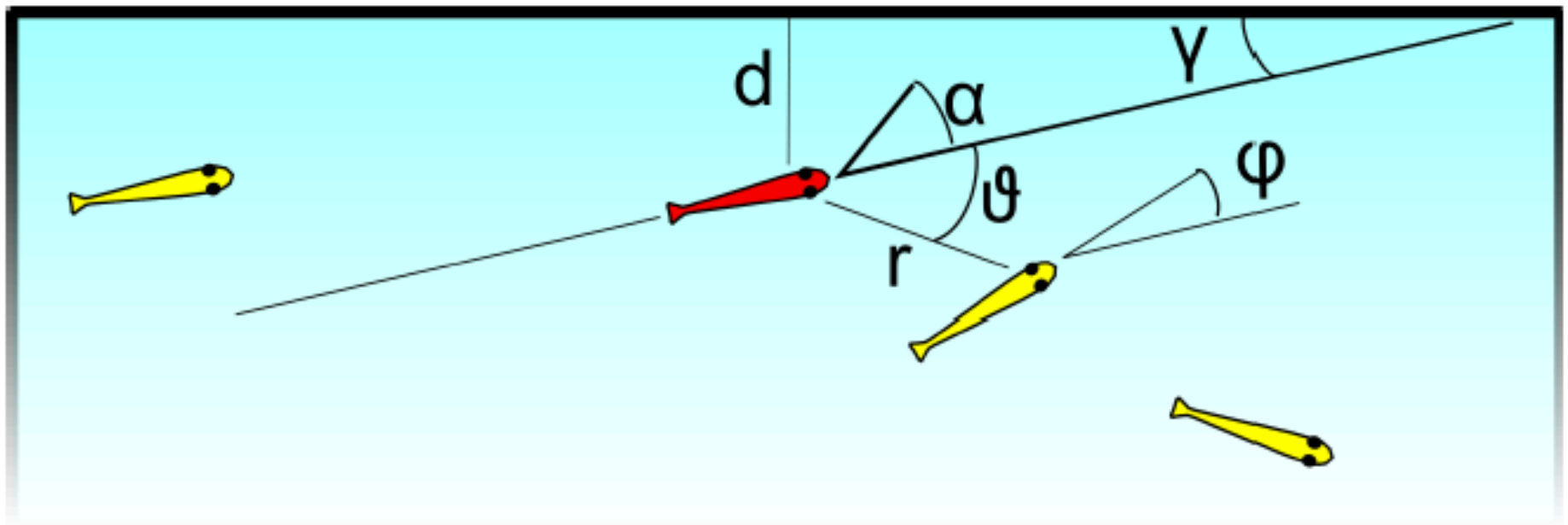






Herbert-Read et al. (2011), *PNAS*

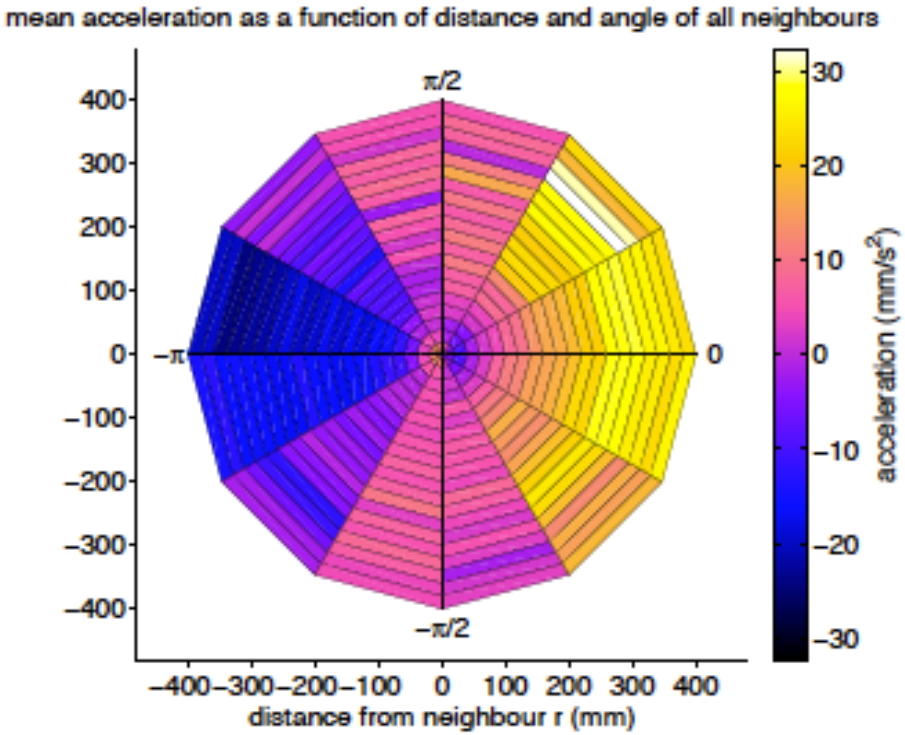
Rules of motion

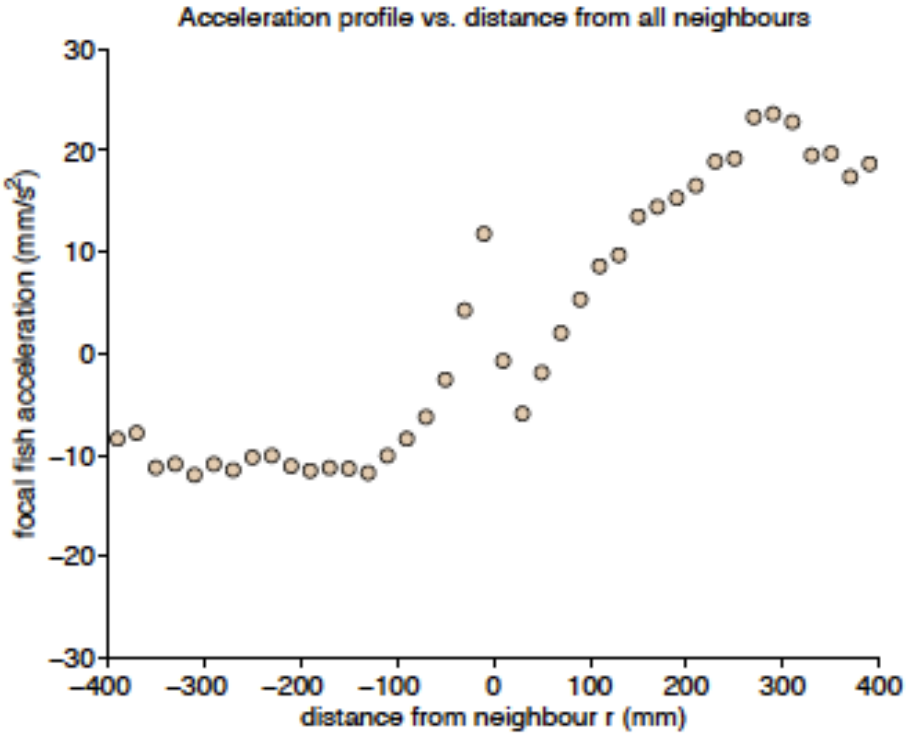


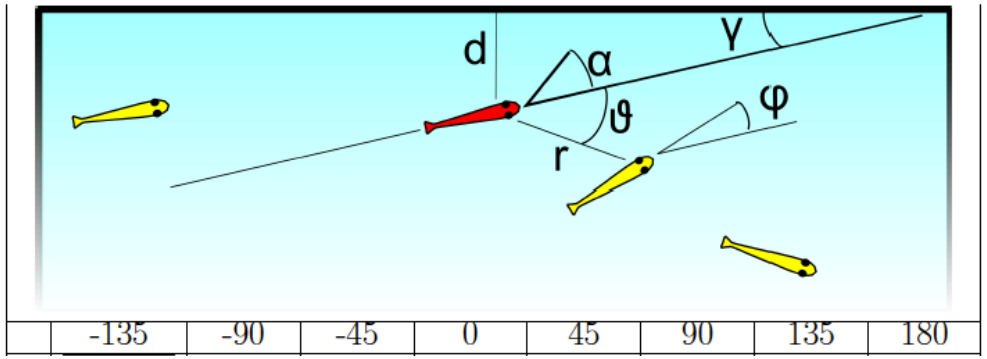
	-135	-90	-45	0	45	90	135	180
γ								
θ								
ϕ								

Herbert-Read et al. (2011), *PNAS*

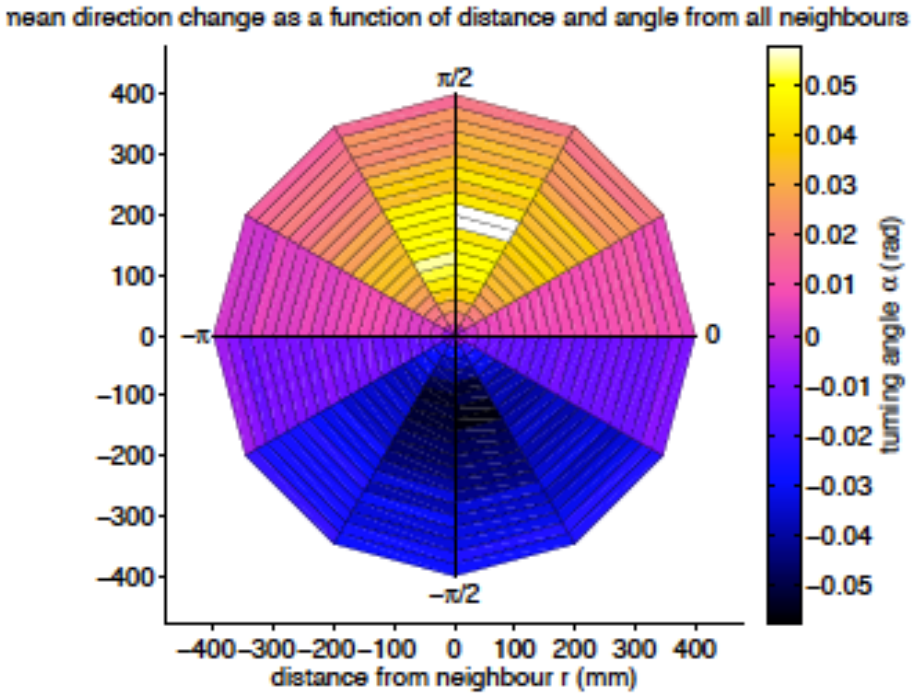
Catch up those in front.
Wait for those behind.

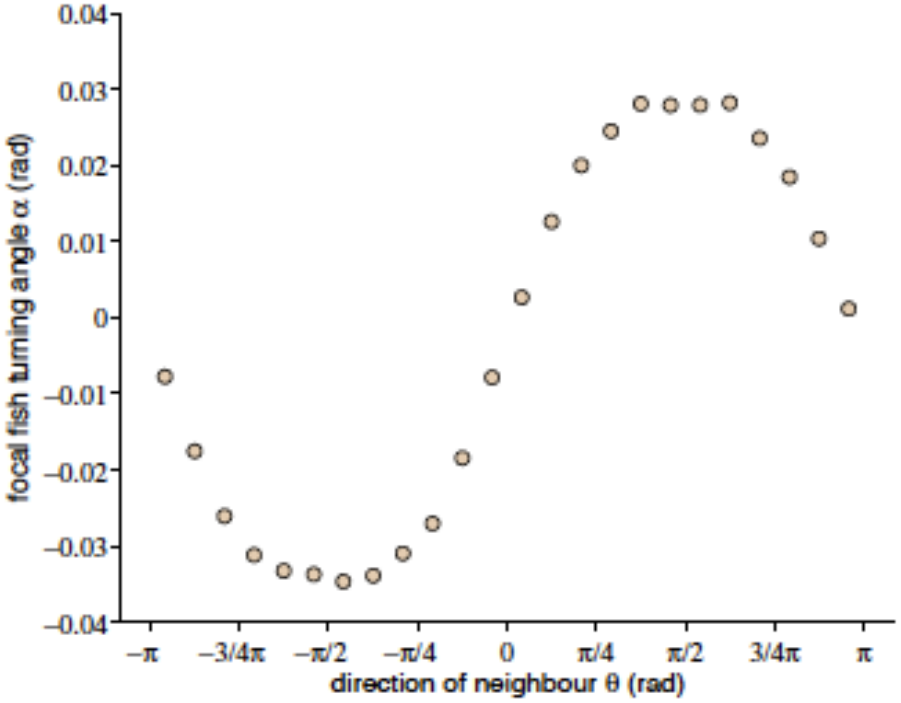


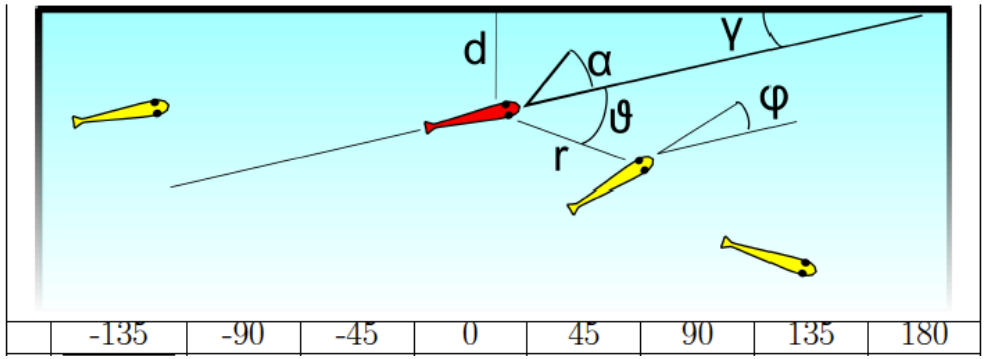




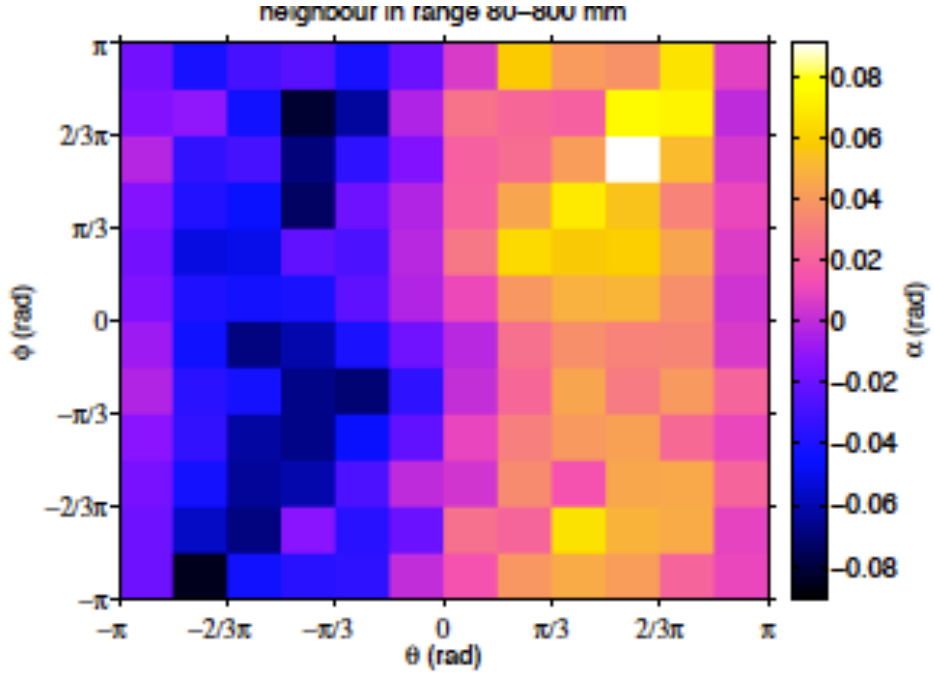
Turn towards your neighbours

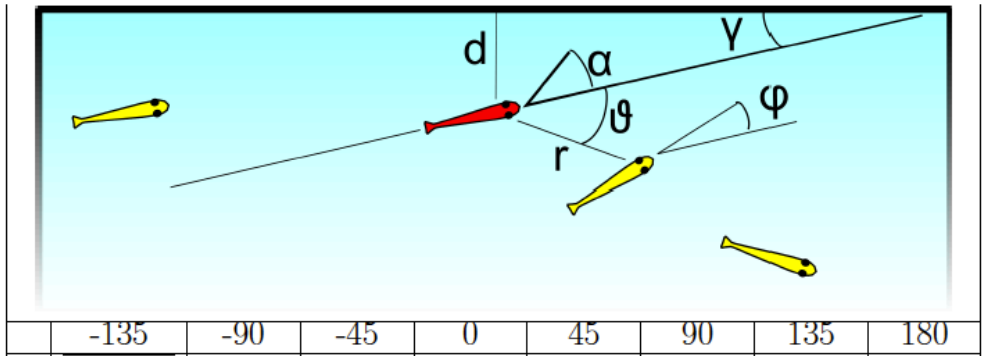




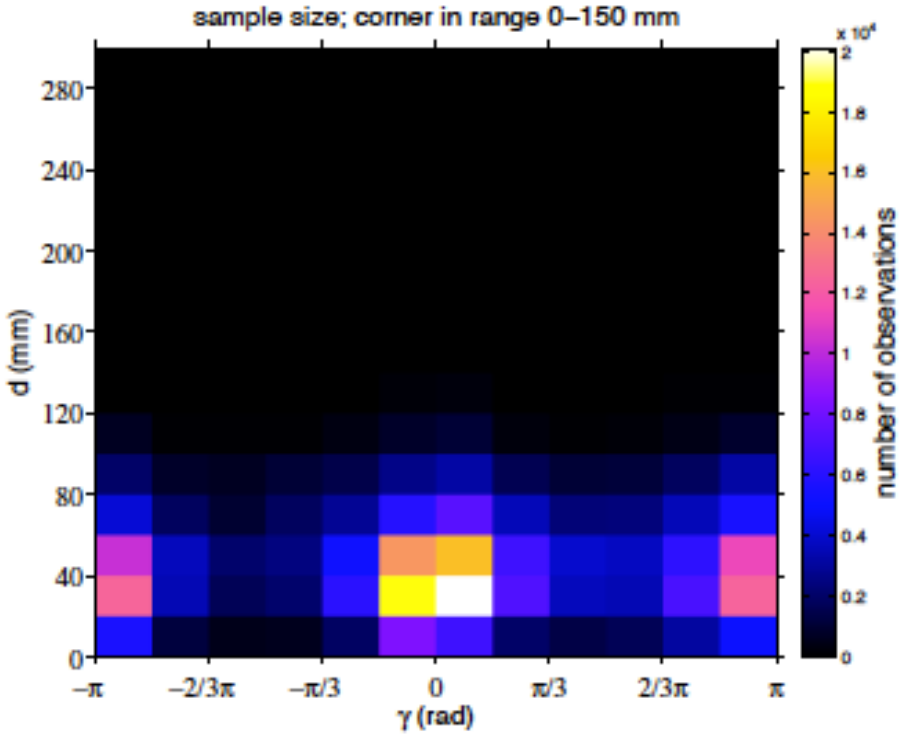


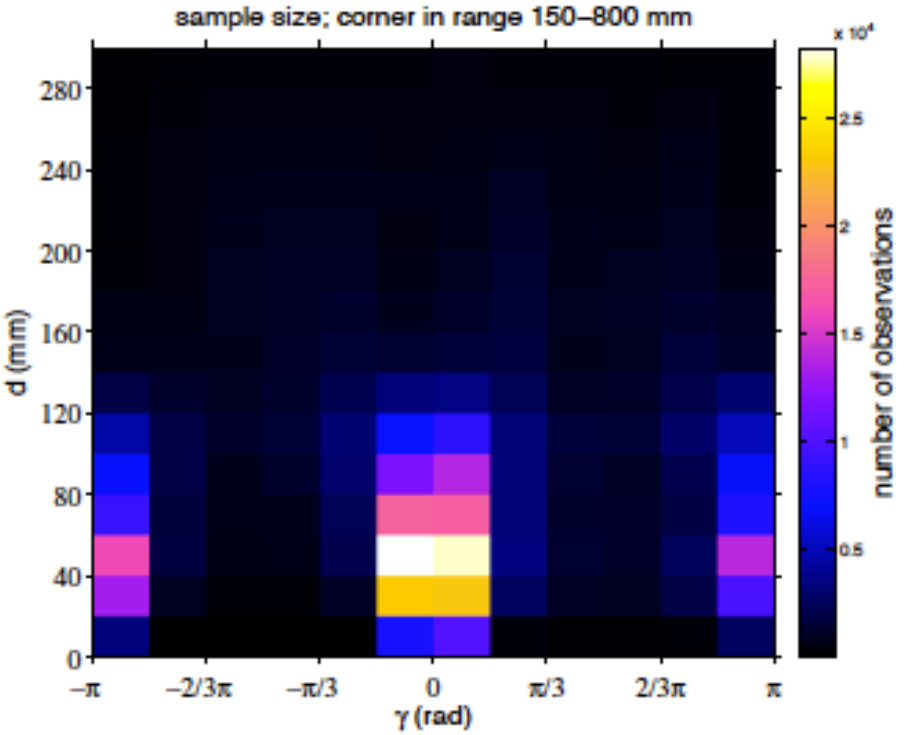
Attraction is more important than alignment

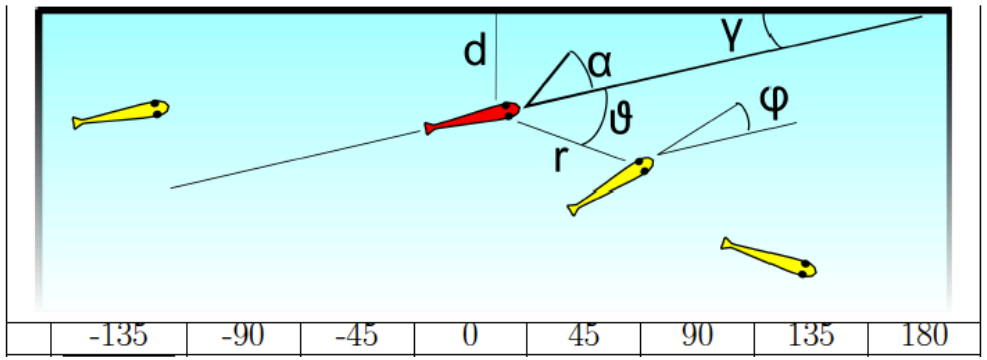


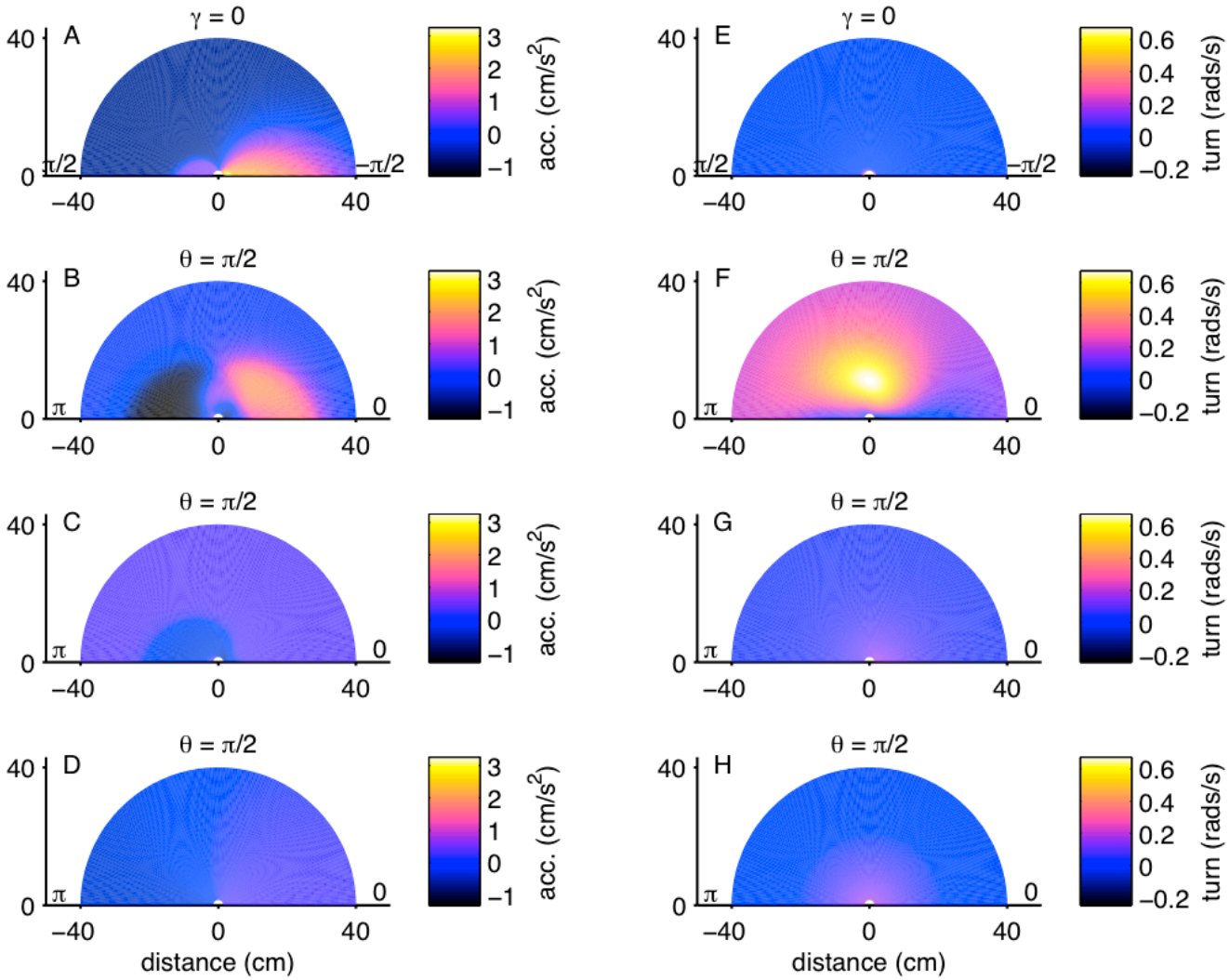


Fish swim parallel to sides of tank



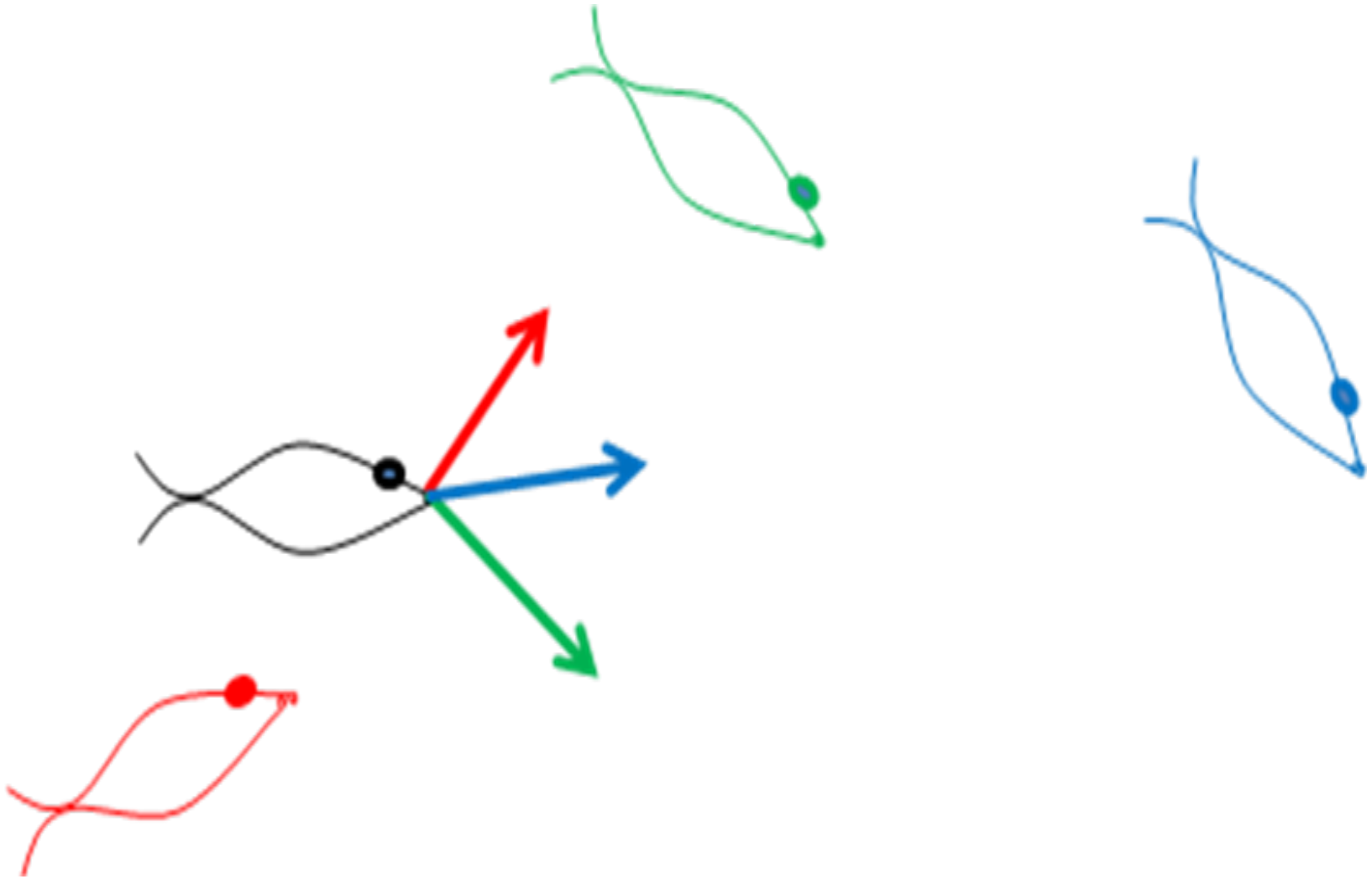




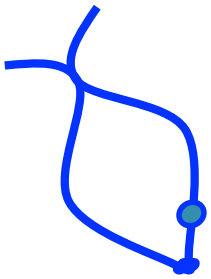


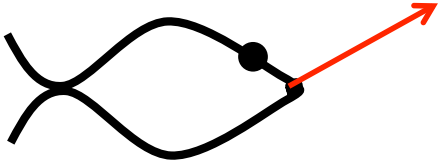
Response = Past + Wall + Neighbour 1 +
Neighbour 2 + Neighbour 3

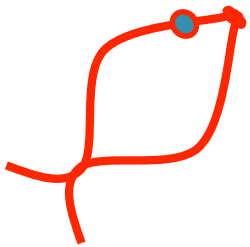
Herbert-Read et al. (2011), *PNAS*



Herbert-Read et al. (2011), *PNAS*







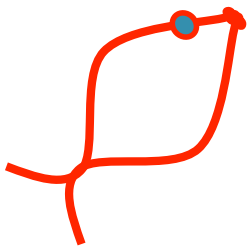
Primarily Nearest Neighbour

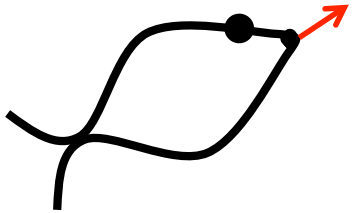
Acceleration Response

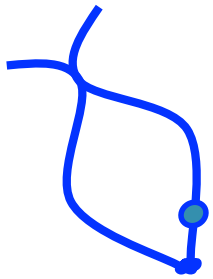
Repulsion/Attraction

Leader/Follower

Herbert-Read et al. (2011), *PNAS*







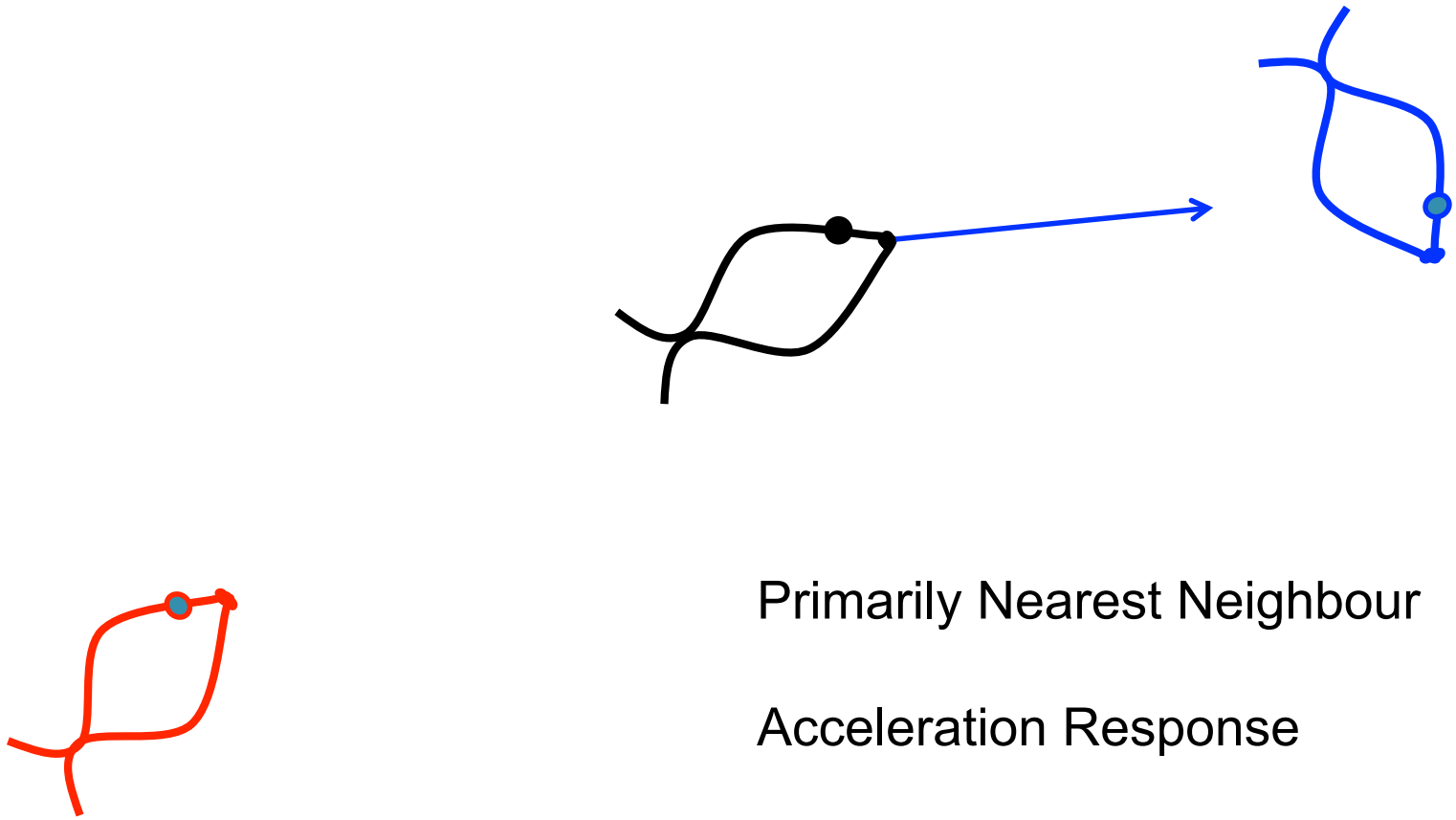
Primarily Nearest Neighbour

Acceleration Response

Repulsion/Attraction

Leader/Follower

Herbert-Read et al. (2011), *PNAS*



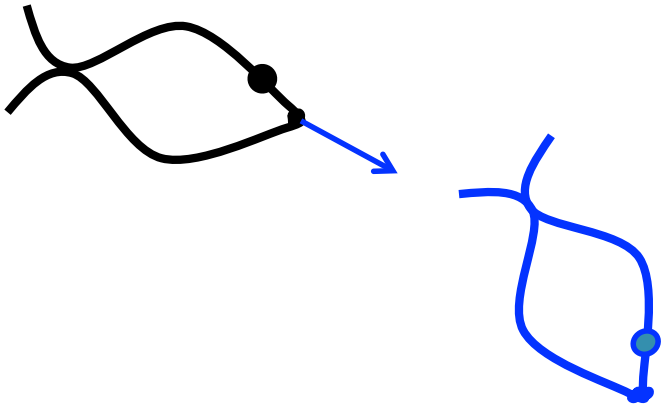
Primarily Nearest Neighbour

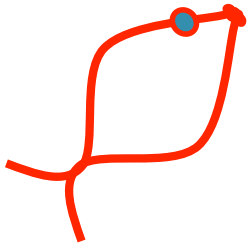
Acceleration Response

Repulsion/Attraction

Leader/Follower

Herbert-Read et al. (2011), *PNAS*





Primarily Nearest Neighbour

Acceleration Response

Repulsion/Attraction

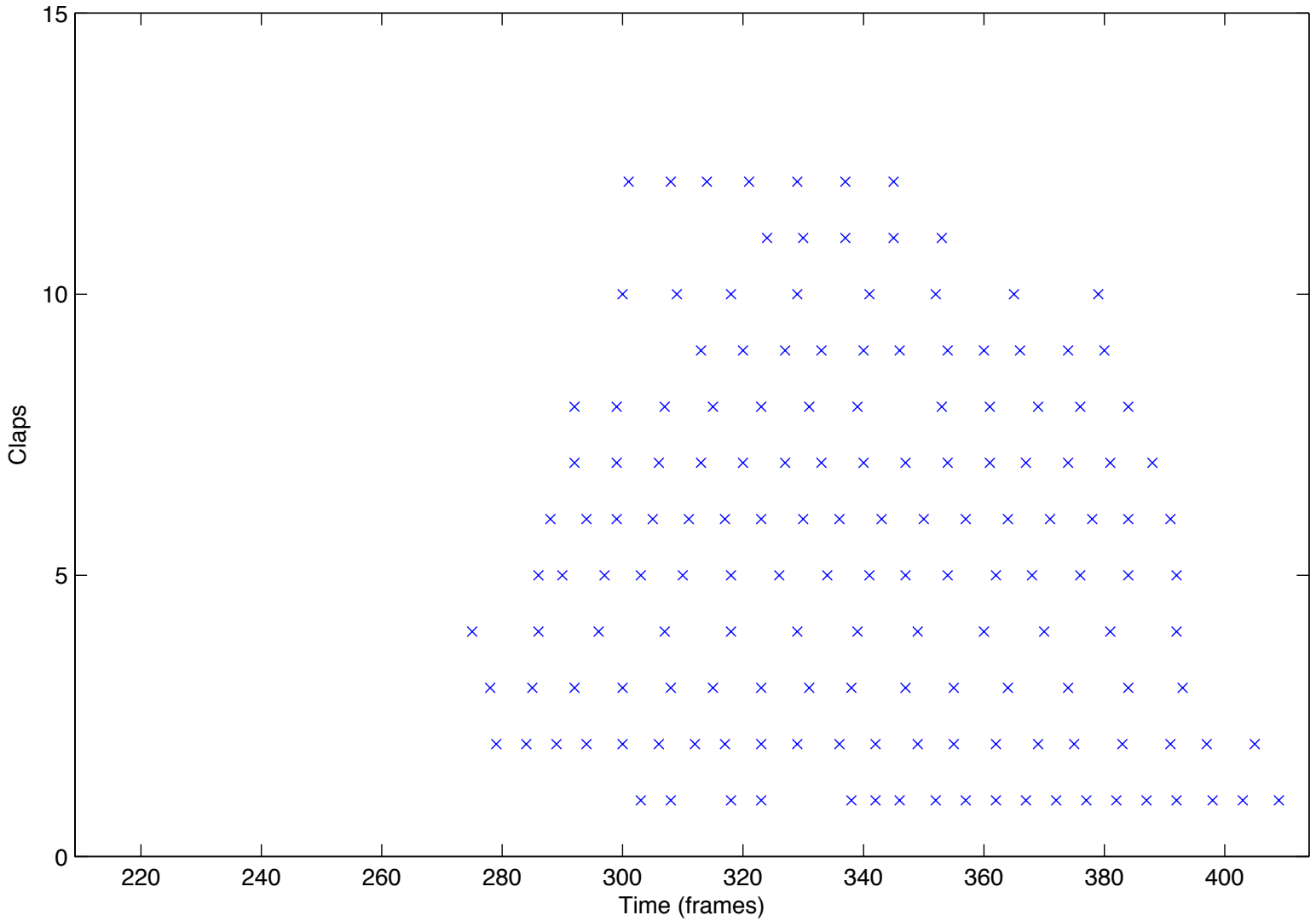
Leader/Follower

Herbert-Read et al. (2011), *PNAS*

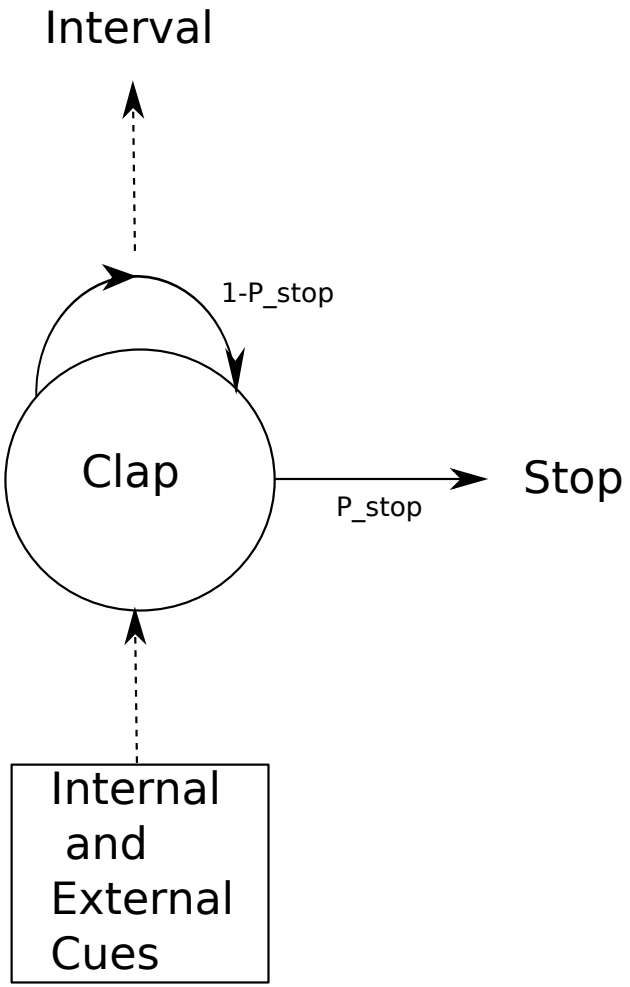
Perna et al. (submitted)

Audience Applause

Audience Applause

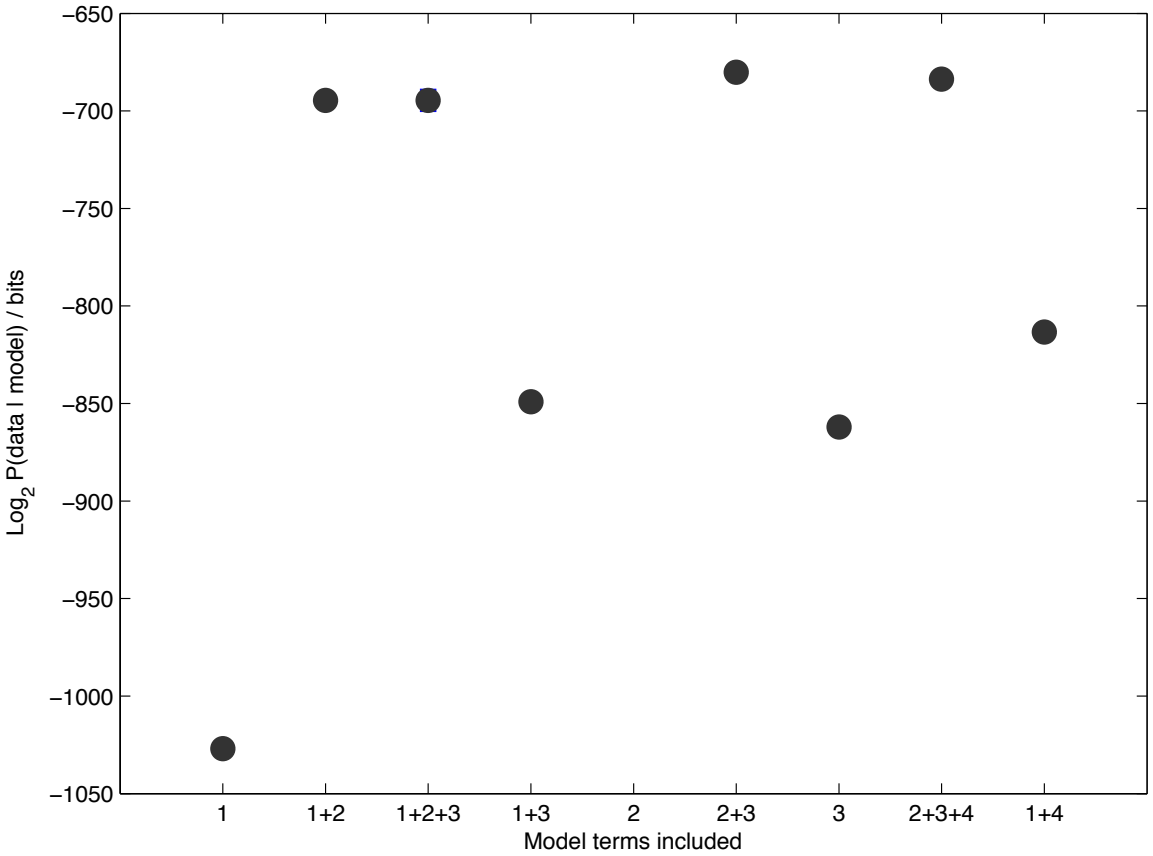


Simple model

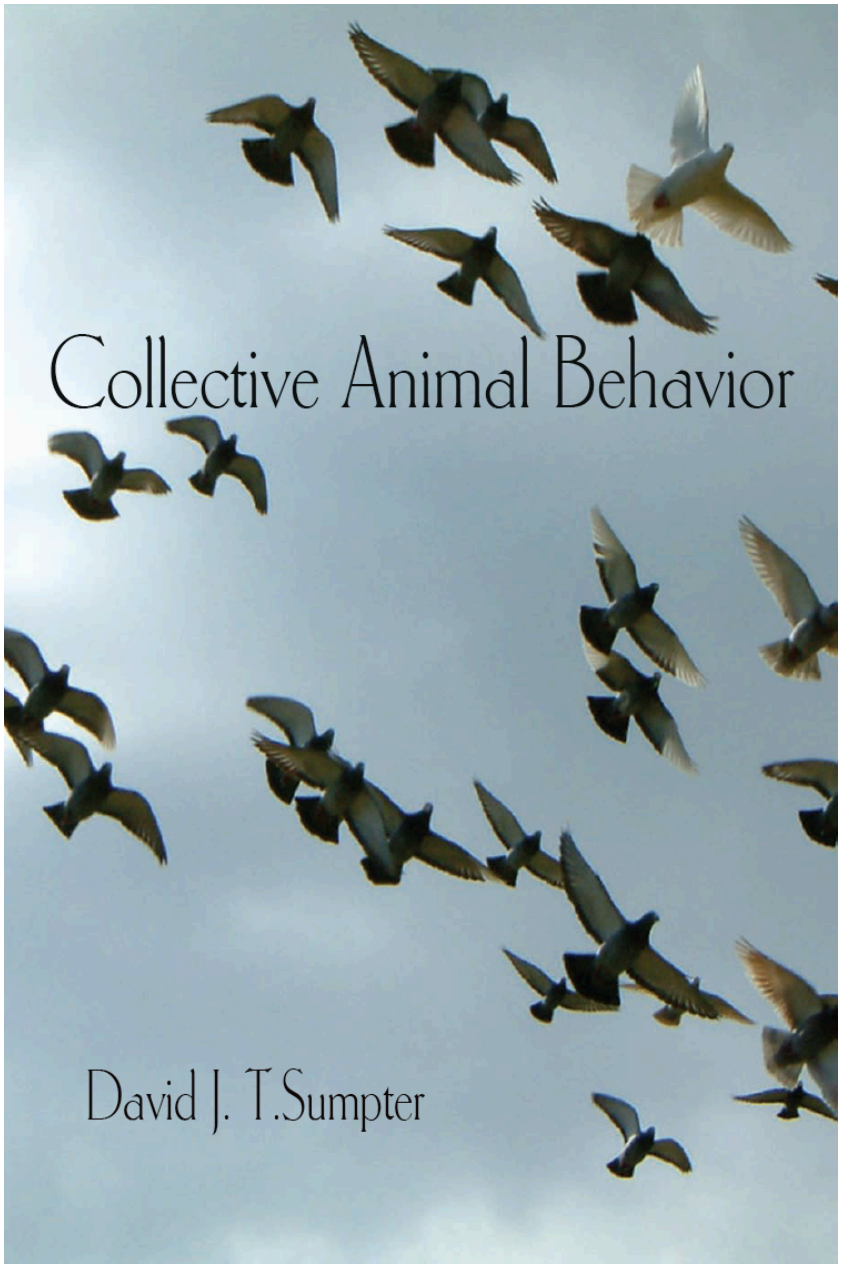


$$P_{\text{stop}} = \lambda_1 + \lambda_2 \rho_{\text{stopped}} + \lambda_3 \frac{n_{\text{claps}}}{\max n_{\text{claps}}} + \lambda_4 \rho_{\text{neighbours stopped}}$$

Bayes factor test



$$P_{\text{stop}} = \lambda_1 + \lambda_2 \rho_{\text{stopped}} + \lambda_3 \frac{n_{\text{claps}}}{\max n_{\text{claps}}} + \lambda_4 \rho_{\text{neighbours stopped}}$$



www.collective-behavior.com

Webpage:

http://www.math.uu.se/~david/

Just now Postdoc position available to work with Jens Krause and myself on human collective behaviour.

http://www2.personalavd.uu.se/ledigaplatser/2450postDOC.html