Emergent Sensing of Complex Environments by Mobile Animal Groups

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Presented by Ryan O'Loughlin and Chandan M S

“Collective intelligence may emerge from interactions between individuals.”

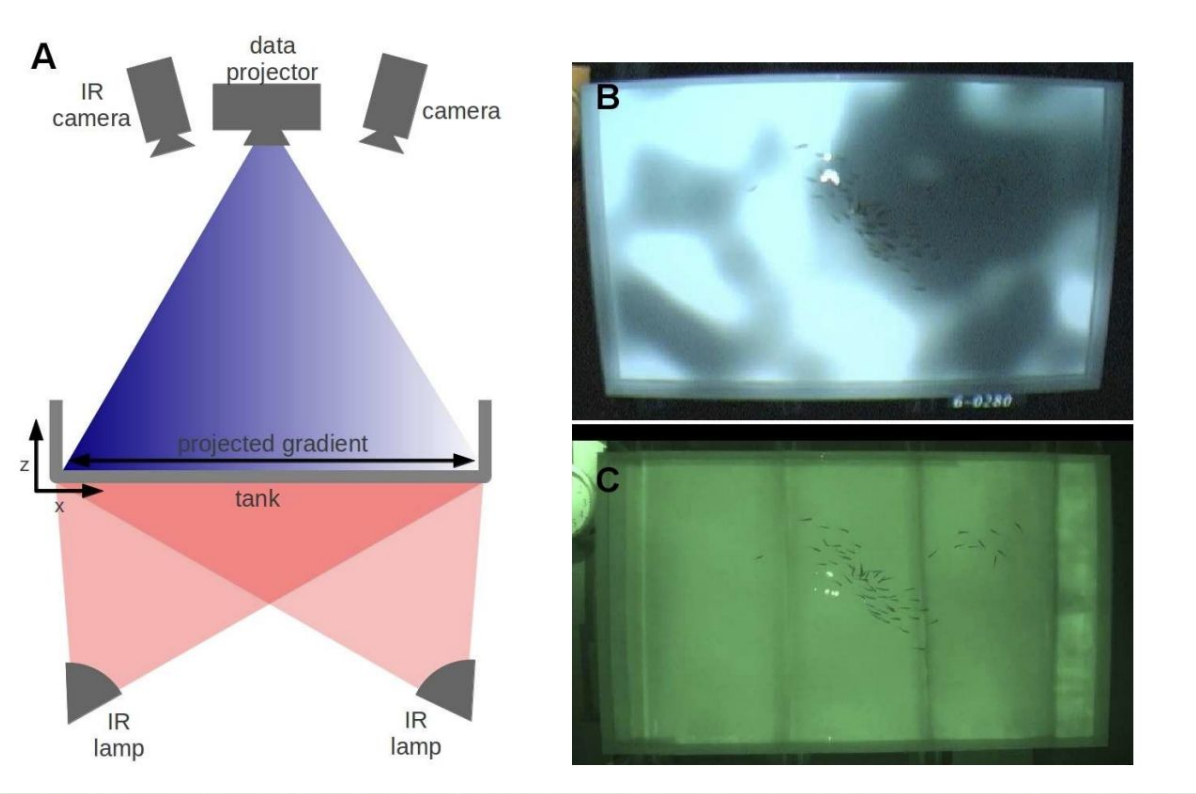
Notemigonus Crysoleucas

- Also known as a “Golden Shiner”
- A small fish (~5cm length)
- Prefers shaded waters


Hello darkness my old friend...

Light as an Environmental Cue

- Because Shiners prefer to avoid light, it thus becomes an environmental cue
- This can then be used to study how golden shiners respond to their environment, in groups and individually
- Berdahl et al. claim light here can stand in for any environmental cue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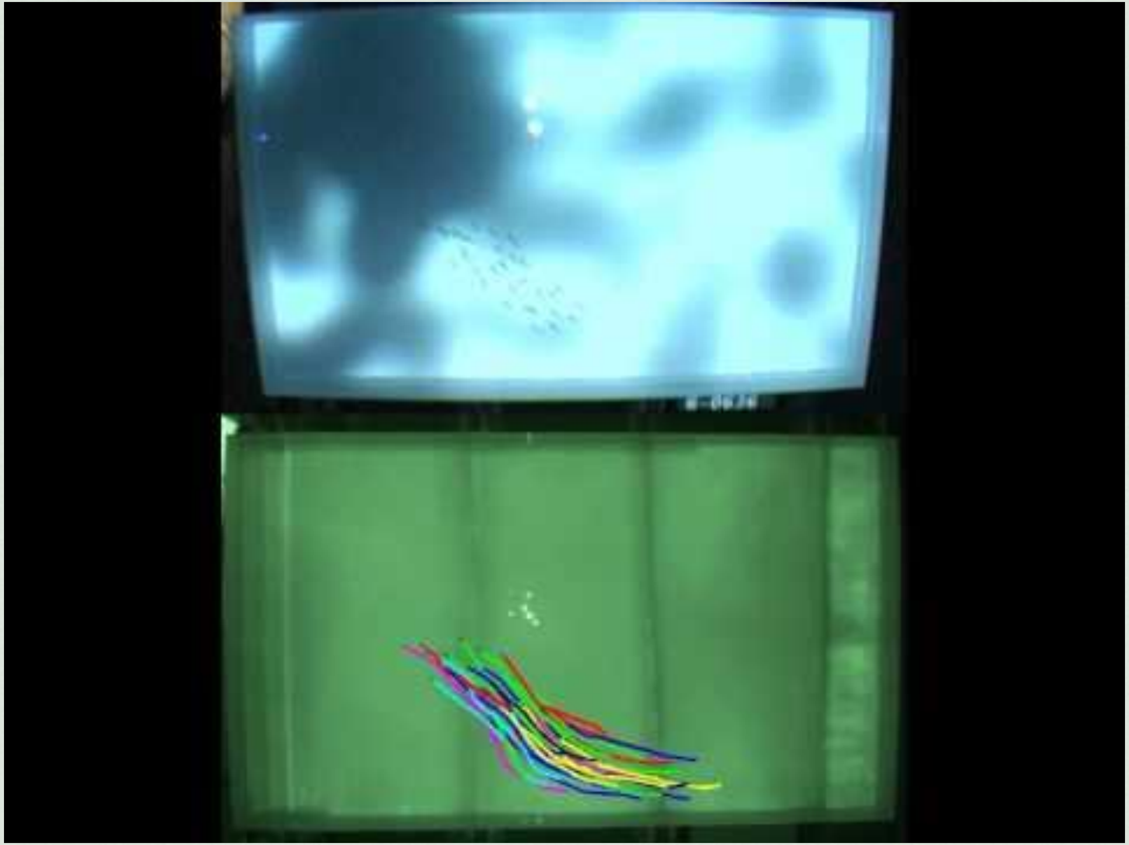


Sensing the Gradient

- To what degree is a collection of golden shiners sensitive to the environmental changes *beyond the ability of any one individual?*

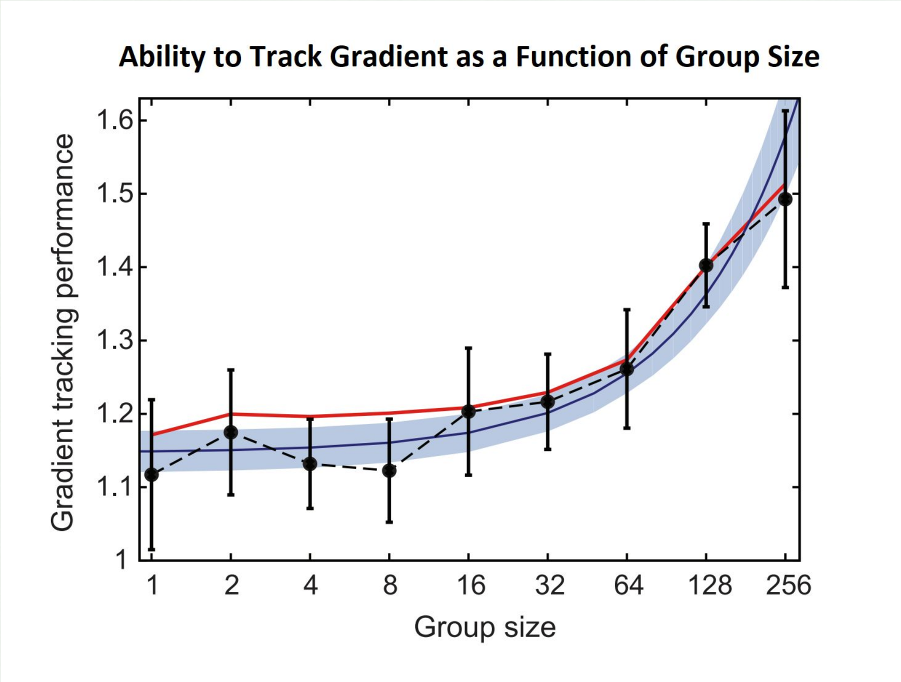
- More fish should be able to better assess the lighting-gradient of their environment

Experimental Features

- S_i : *Social vector* defined by direction of *conspecifics*
- G_i : Environmental vector defined by the direction of steepest ascent (or descent) into darkness, with a magnitude proportional to rate of increase
- Ψ : *Performance metric* defined by the average darkness level per fish, averaged across all fish, averaged over time

Group Performance

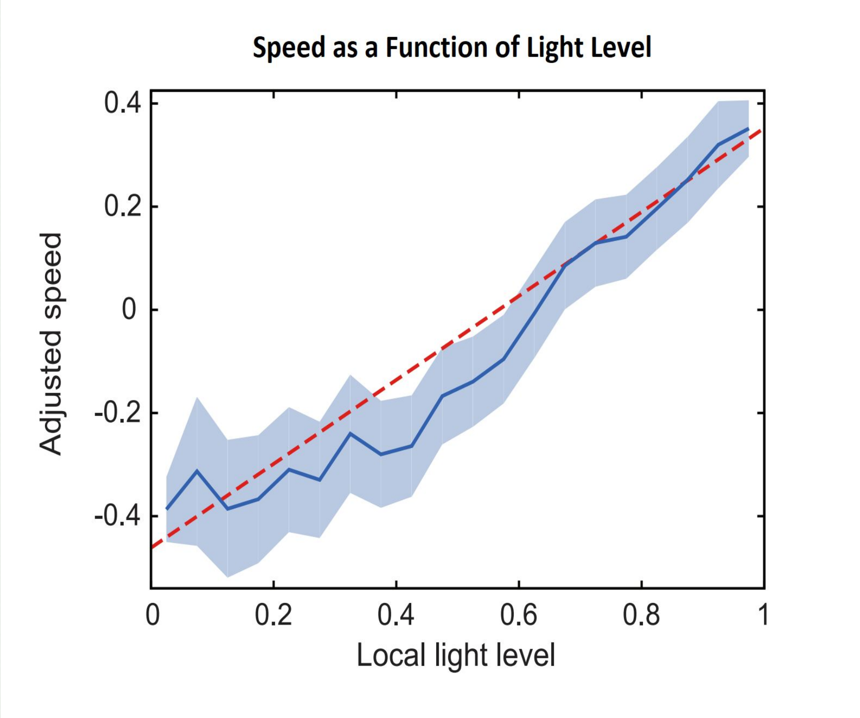
- *The performance metric is positively related to school size*
- Computational model (red) achieves similar results



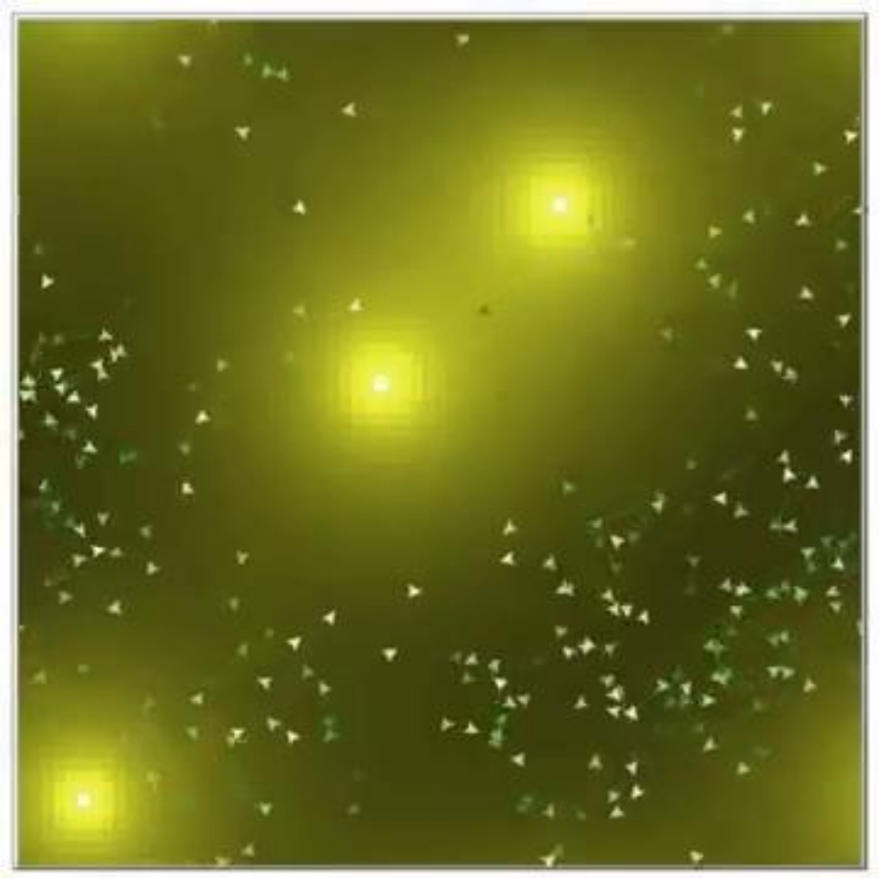
Speed and Light

- Fish travel more slowly in dark regions (and quicker in bright)

- This creates a turning motion for flocks that partially enter a light region (away from the light)



NetLogo model for static lights and light based speed change

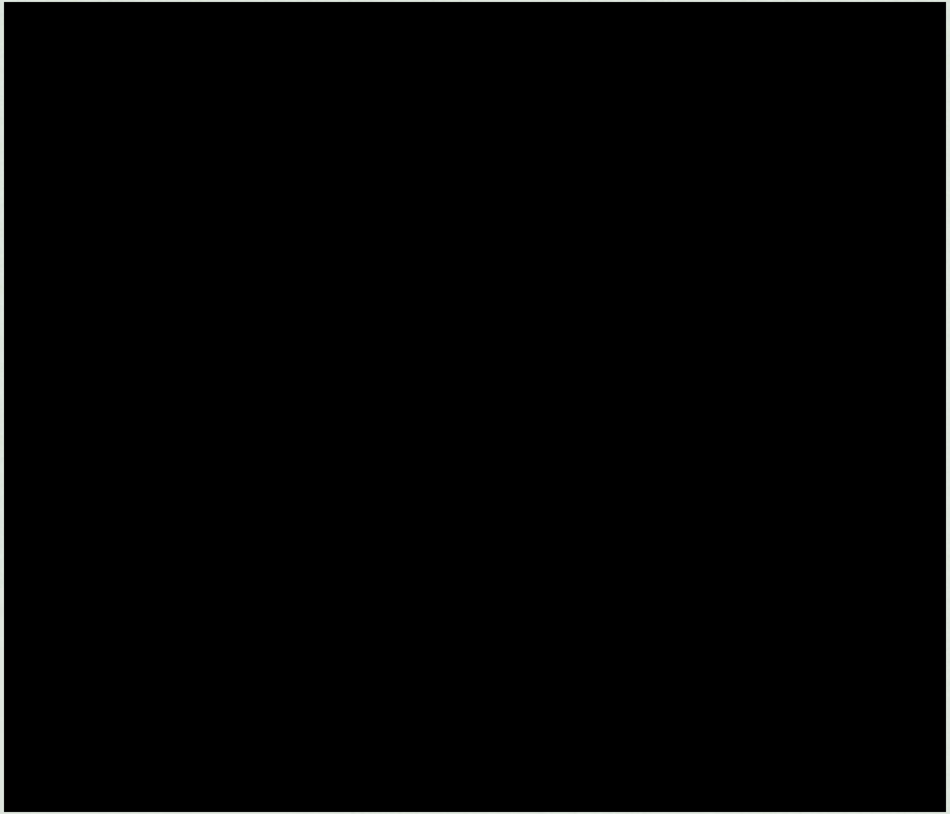


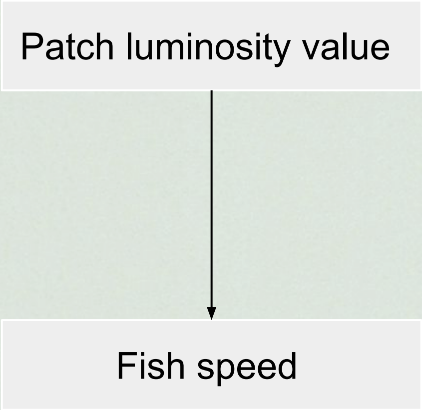
Primary Research Questions

- *Is the positive correlation between group size and performance a result of self-organization?*

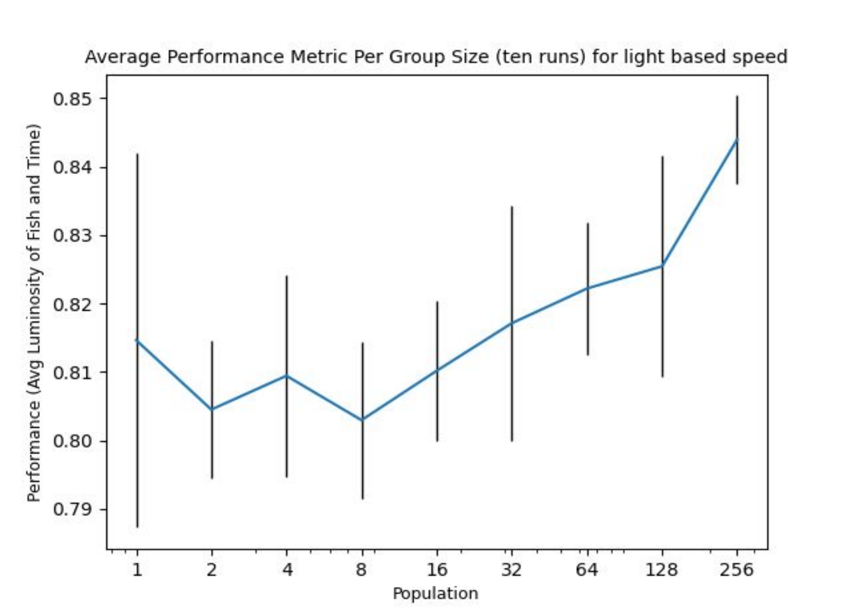
- *Can the empirical results be reproduced with only flocking and light-based speed adjustment, as Berdahl et al suggest?*

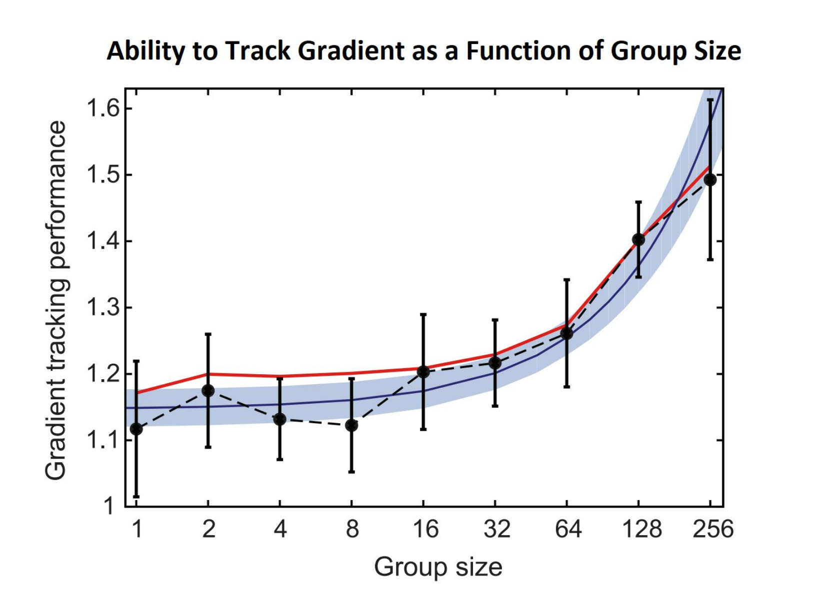
NetLogo model for static lights and light based speed change



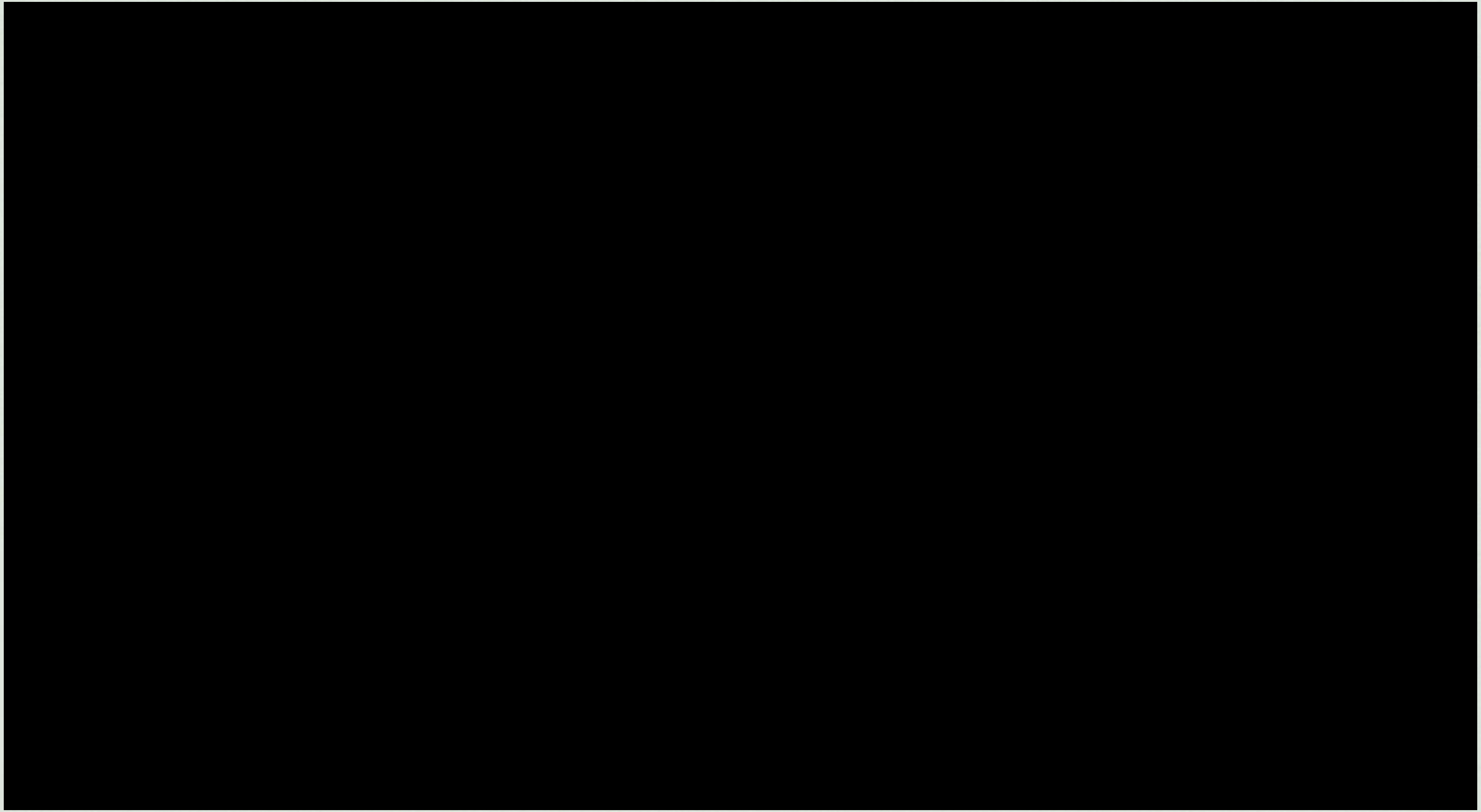


Comparative results with Berdahl's paper

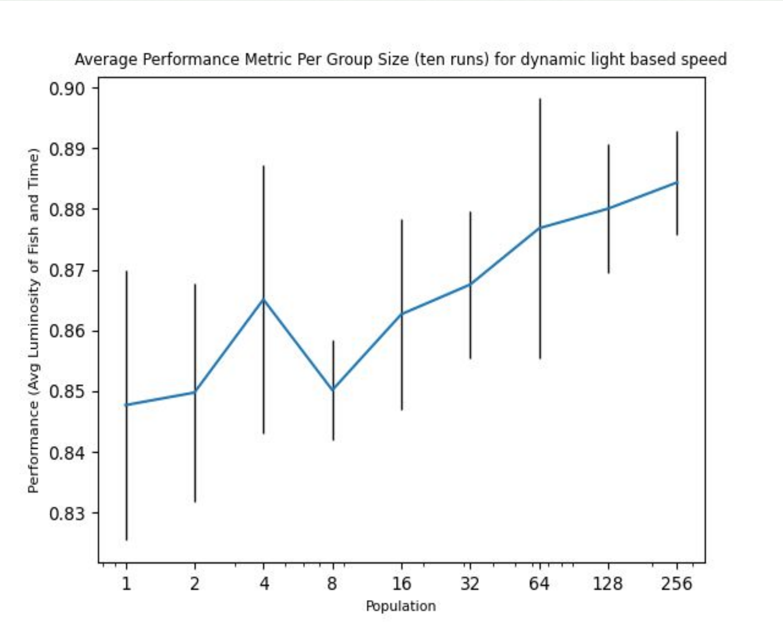




NetLogo model for dynamic lights and light based speed change



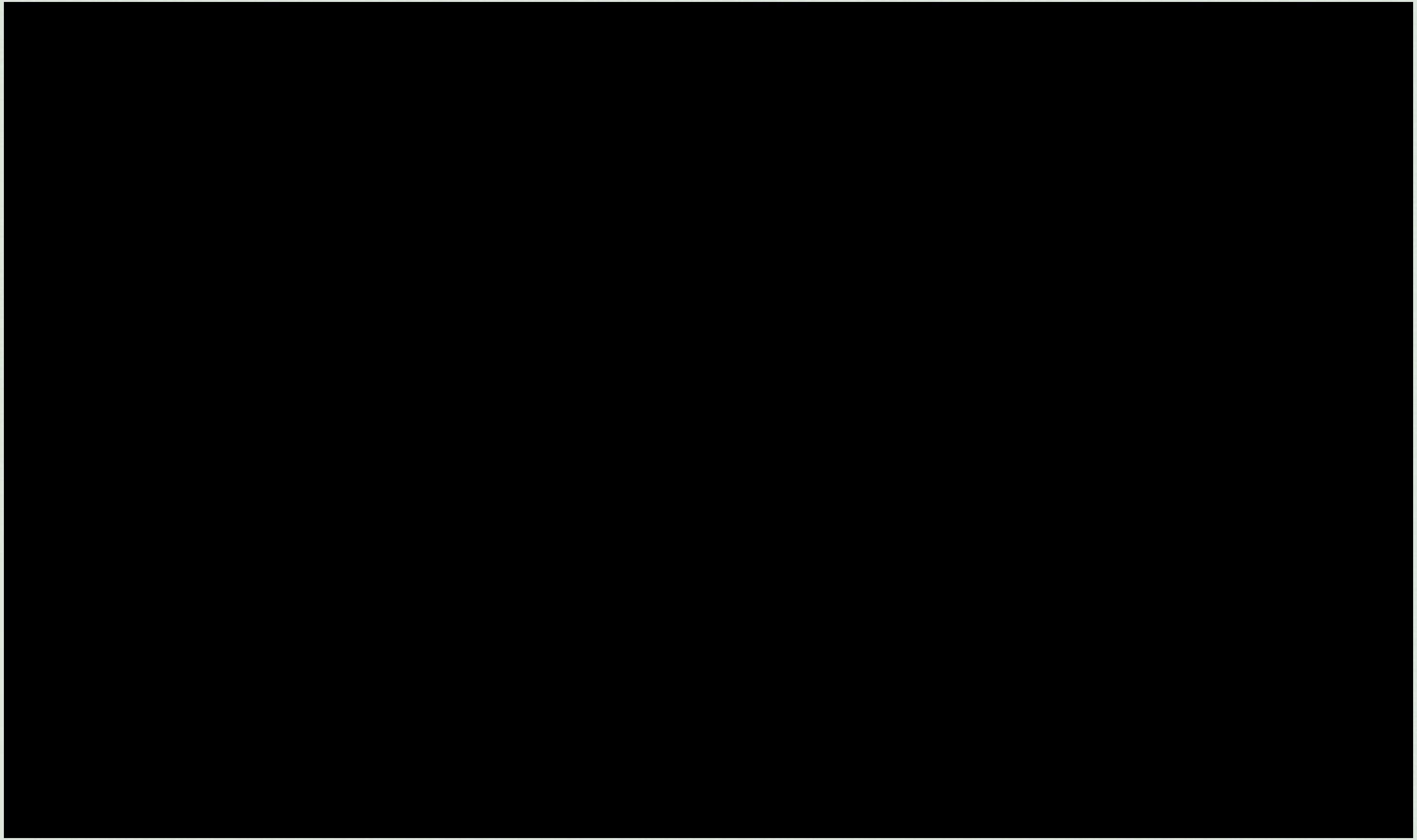
Performance results for dynamic light



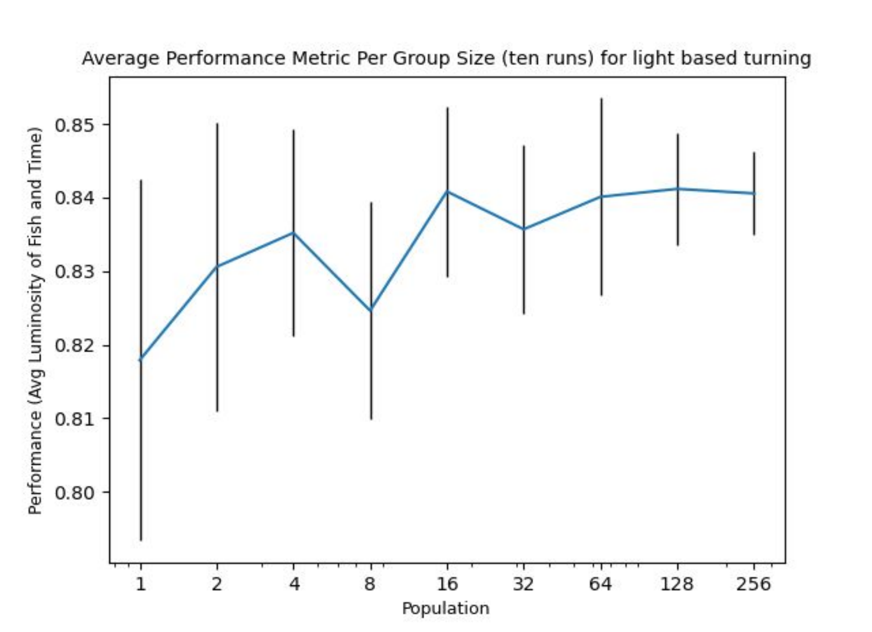
Secondary Research Question

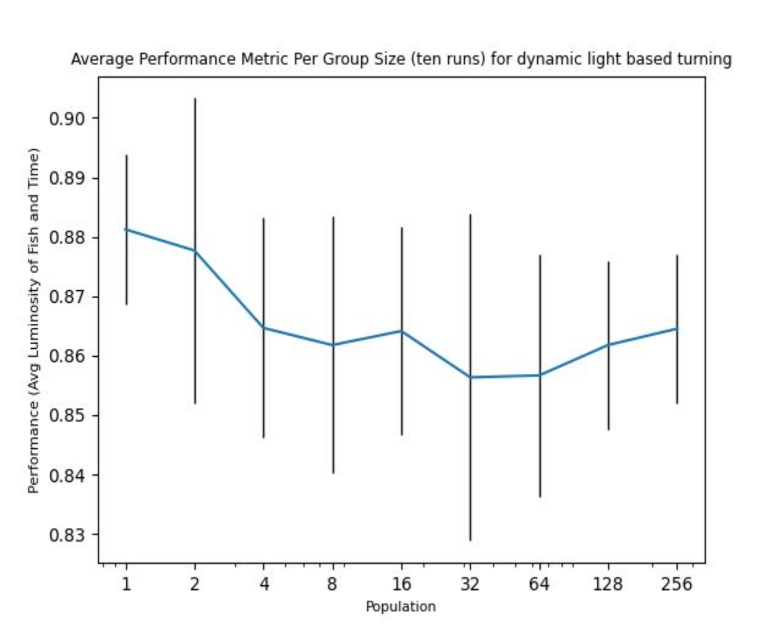
- *Alternatively, could these results be just as well reproduced by another type of reaction to the gradient--such as simply turning away from light?*

NetLogo model for static lights and light based turning



Performance results for turning based model





Concluding Remarks

- Empirically, a Golden Shiner school is ***more than the sum of its parts***
- In terms of reproducing this emergent property of the Berdahl et al. experiment, the speed-based models are more representative
- Turning based models have a similar property when the static light is used. However, speed based models produce better group-size performance correlation and self-organising behaviour in dynamic lights.

Relevant Papers

- Berdahl, Andrew, et al. "Emergent sensing of complex environments by mobile animal groups." Science 339.6119 (2013): 574-576.
- Grünbaum, Daniel. "Schooling as a strategy for taxis in a noisy environment." Evolutionary Ecology 12.5 (1998): 503-522.
- Hemelrijk, Charlotte K., and Hanno Hildenbrandt. "Self-organized shape and frontal density of fish schools." Ethology 114.3 (2008): 245-254.
- Huth, Andreas, and Christian Wissel. "The simulation of the movement of fish schools." Journal of theoretical biology 156.3 (1992): 365-385.

Image Credits

- Fish: *https://en.wikipedia.org/wiki/Golden_shiner*
- Gradient Descent: *https://medium.com/swlh/machine-learning-fundamentals-2-gradient-descent-algorithm-6c8f5204bd9b*
- Gradient Vector Field: *https://malarney.github.io/vector-calc-visualization/*
- Plots: *Directly from paper*


Thanks
For your
attention!

Equations From Berdahl et al. Paper

$$\psi = \left\langle \langle 1 - L \rangle_{fish} \right\rangle_t \qquad \Psi = \psi / \psi_{null}$$

$$\mathbf{S}_i = \sum_{j \in r_s, j \neq i} \frac{\mathbf{c}_j - \mathbf{c}_i}{|\mathbf{c}_j - \mathbf{c}_i|} \qquad \mathbf{G}_i = -\nabla L \Big|_{\mathbf{c}_i} = -\hat{\mathbf{x}} \frac{\partial L}{\partial x}\Big|_{\mathbf{c}_i} - \hat{\mathbf{y}} \frac{\partial L}{\partial y}\Big|_{\mathbf{c}_i}$$

$$\text{individual response to social vector} = \left\langle \frac{\mathbf{S}_i}{|\mathbf{S}_i|} \cdot \frac{\mathbf{a}_i}{|\mathbf{a}_i|} \right\rangle_t$$

$$\text{individual response to environmental vector} = \left\langle \frac{\mathbf{G}_i}{|\mathbf{G}_i|} \cdot \frac{\mathbf{a}_i}{|\mathbf{a}_i|} \right\rangle_t$$