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Effects of burst-and-coast duty cycle on collective behavior in a fish school model

Collective behavior 2025/2026

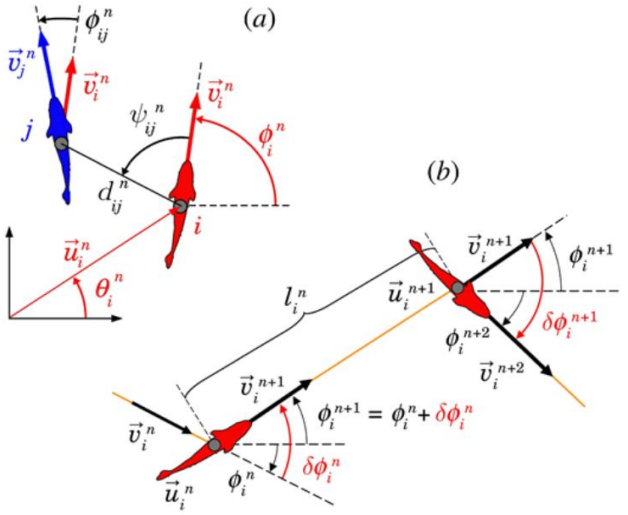
12th of January, 2026

Problem

- Problem: burst-and-coast swimming
- Goal:
  - Re-implement the original article
  - Extend with:
    - Duty cycle
    - Decision steps

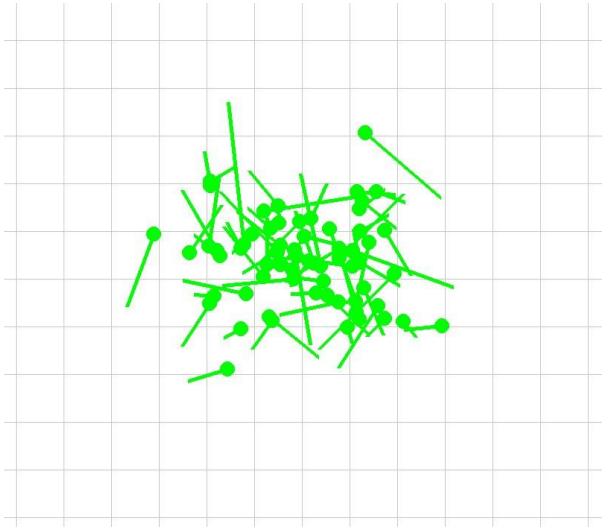
Baseline model

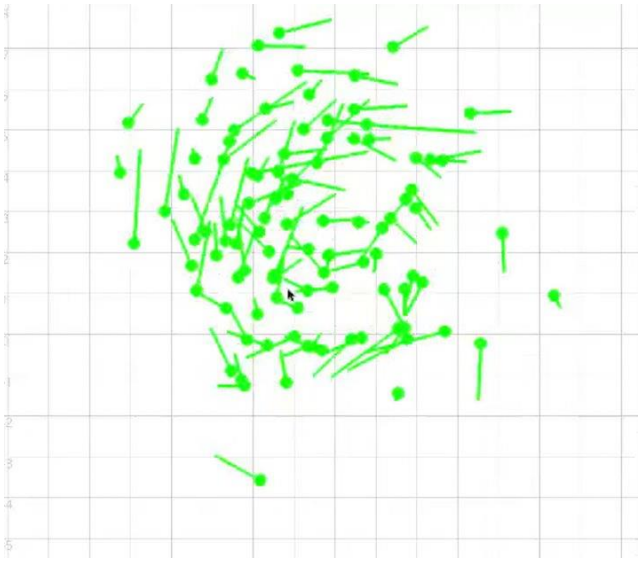
- Heading selection
- Burst phase (kick)
- Coast phase
- Repeat

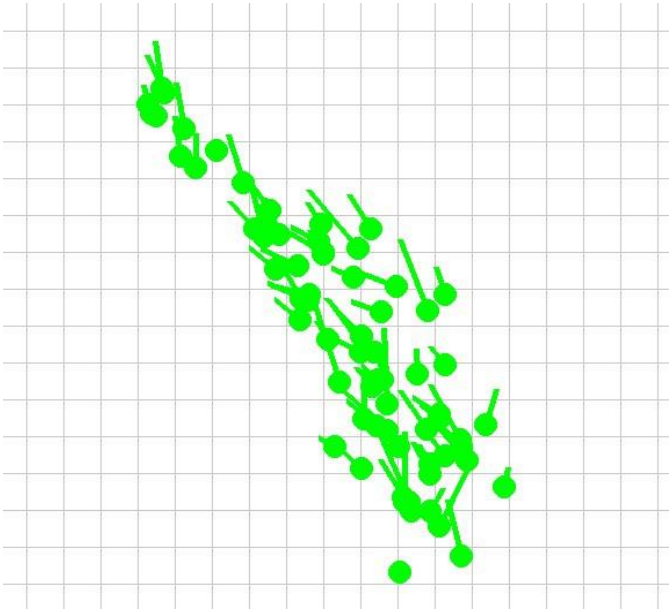


Source: Wang et al.

- Python, numpy, pygame
- Discrete movement: instantaneous heading updates and position jumps







Extended model

- Implements continuous velocity integration
  - Duty cycle (ω):
    - Controls burst vs coast duration
  - Number of decision steps (n_ω)
    - Controls granularity of heading updates

$$\tau_{\text{burst}} = \omega \cdot \tau$$
$$\tau_{\text{coast}} = (1 - \omega) \cdot \tau$$

Evaluation

- Group dispersion:
  - how much the fish are spread out

$$D(t) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \|\mathbf{u}_i(t) - \mathbf{u}_B(t)\|^2}$$

- Group polarization
  - How aligned headings of fish are

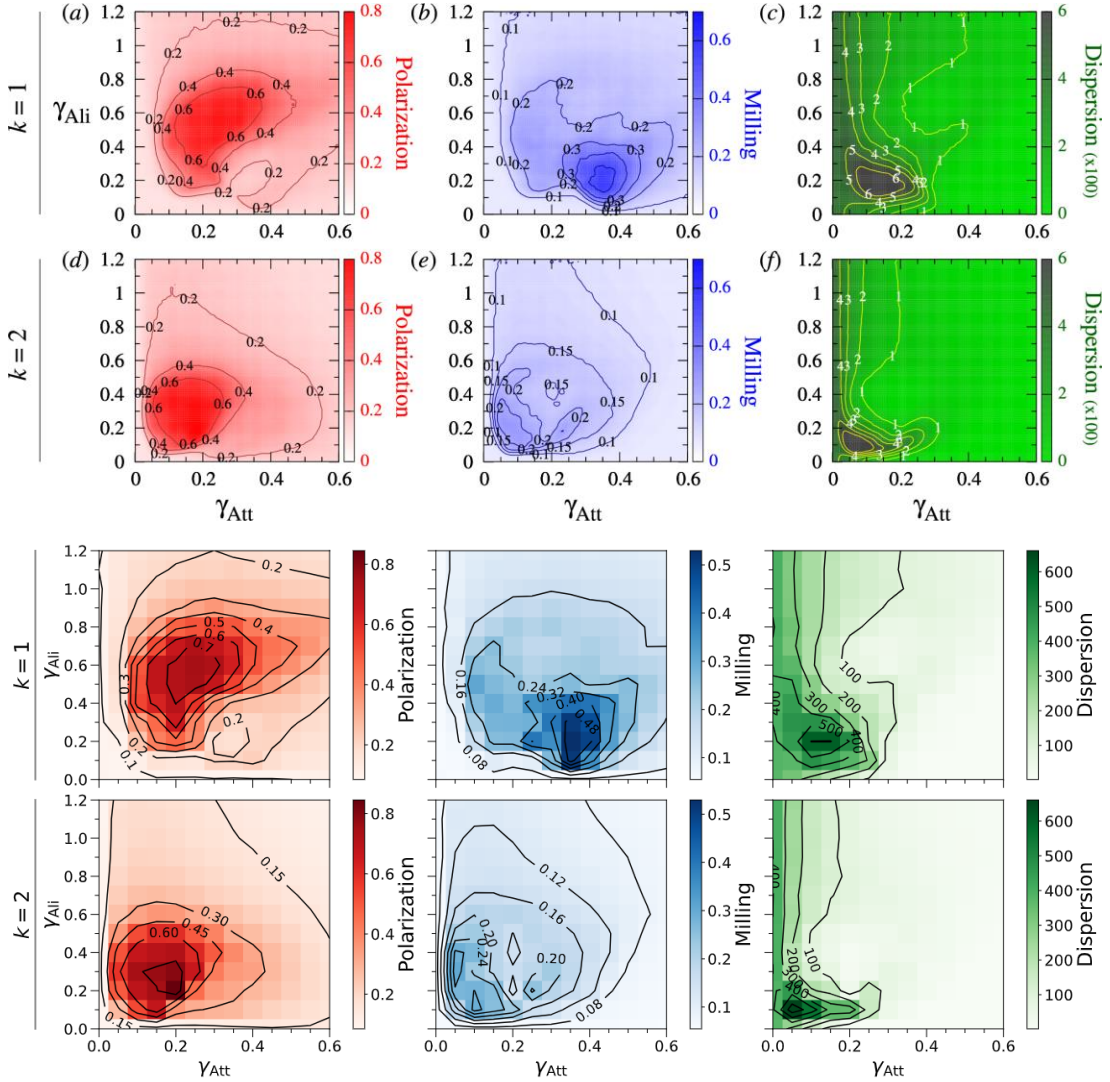
$$P(t) = \left\| \frac{1}{N}\sum_{i=1}^{N} \frac{v_i(t)}{\|v_i(t)\|} \right\|$$

- Milling index
  - how much the fish are swimming around a barycenter in a circular fashion

$$M = \left| \frac{1}{N}\sum_{i=1}^{N} \sin\left(\bar{\theta}_w^i(t)\right) \right|$$

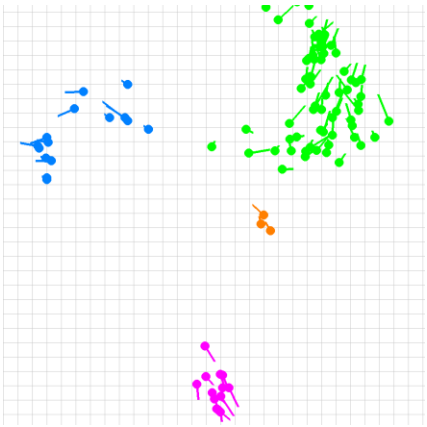
Results (base model)

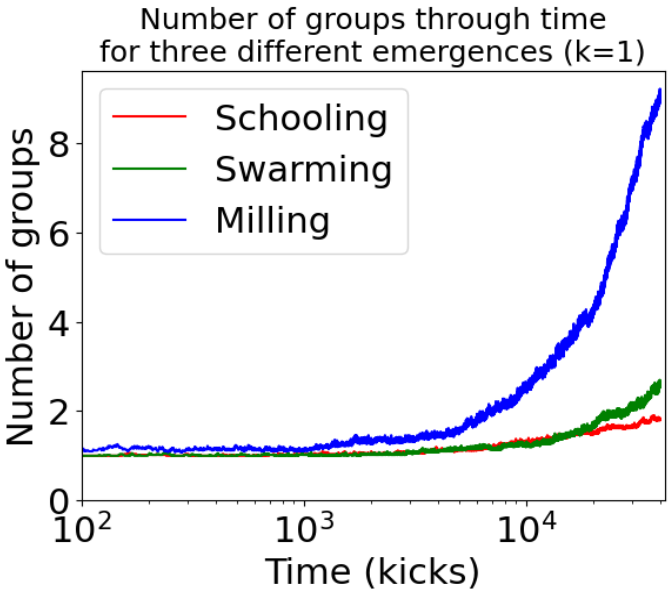
- Original vs base

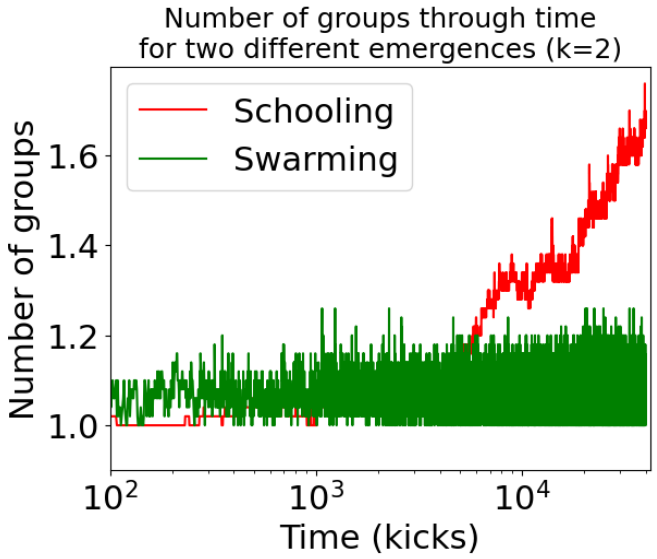


Results: number of groups

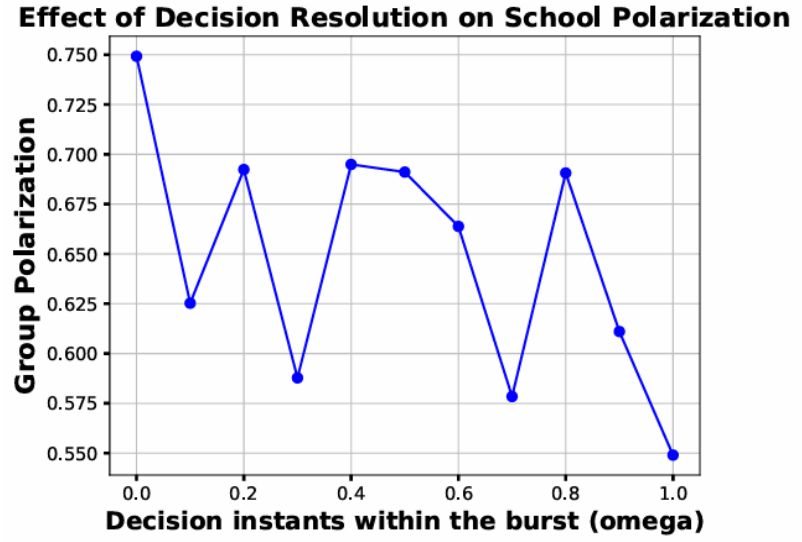
- Track number of groups over time
- Start with sequence of fish, separated by less than critical distance
- Merge groups that have at least one pair of fish, separated by less than merging distance

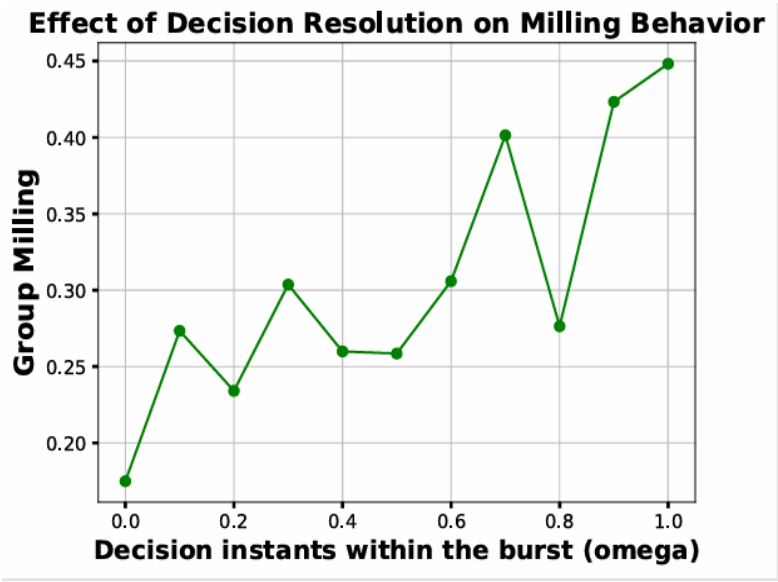




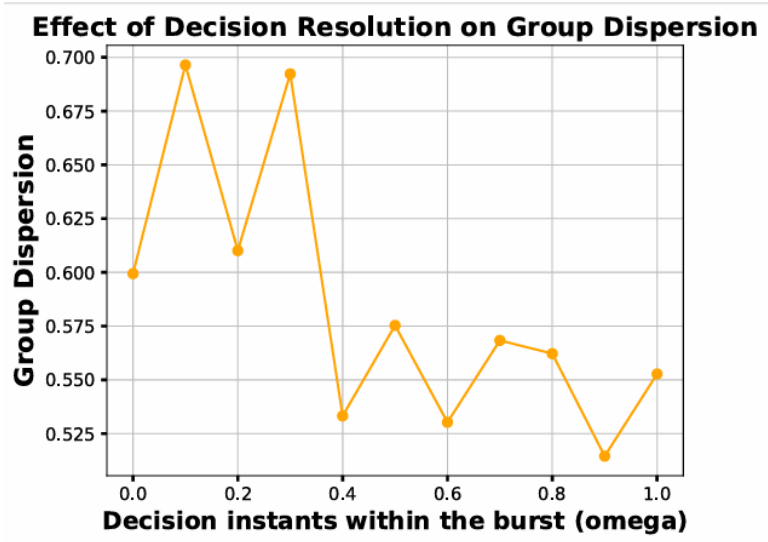


Impact of ω

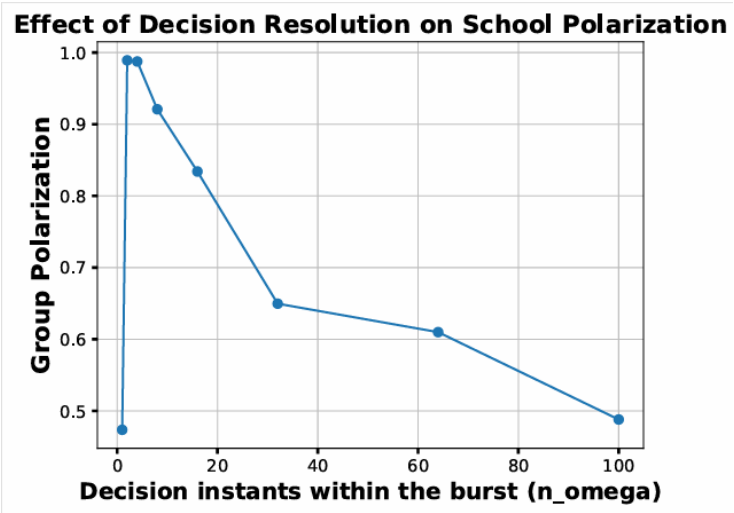


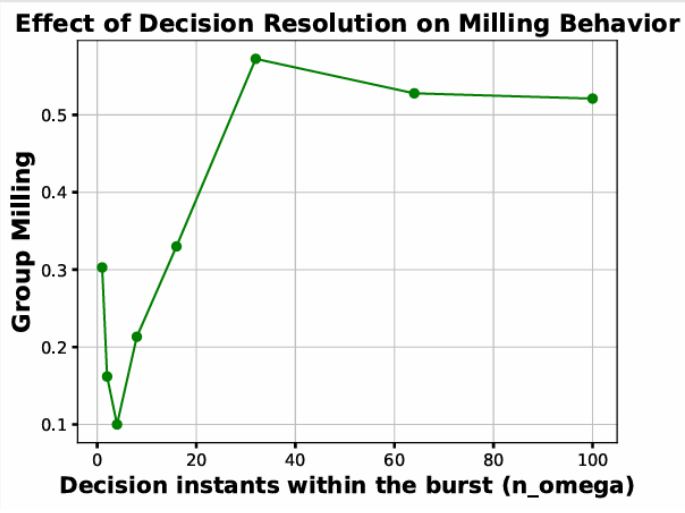


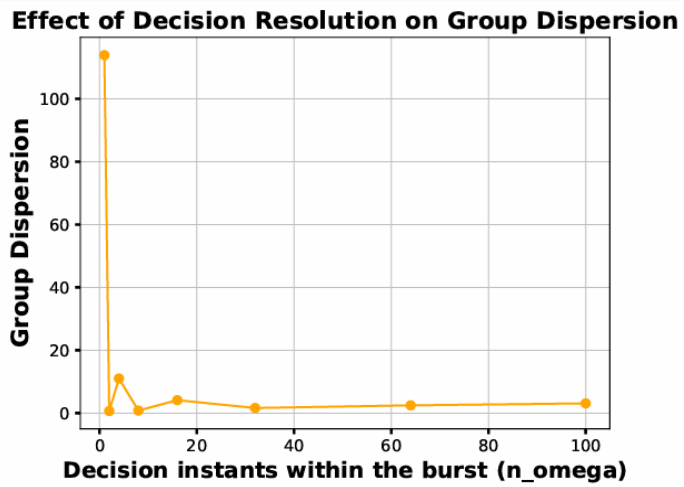
- Low ω:
  - short bursts, long coasts
  - High dispersion, fewer alignment opportunities, cheaper mistakes
- Intermediate ω:
  - High polarization, stable cohesion
- High ω:
  - Velocity magnitude stays high
  - Overshooting, continuous turning -> decreased polarization



Impact of N_ω



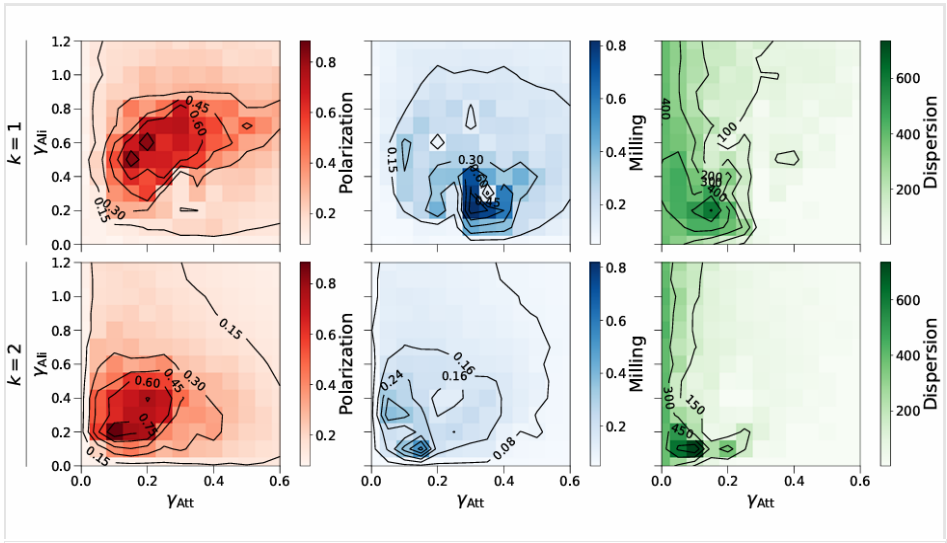




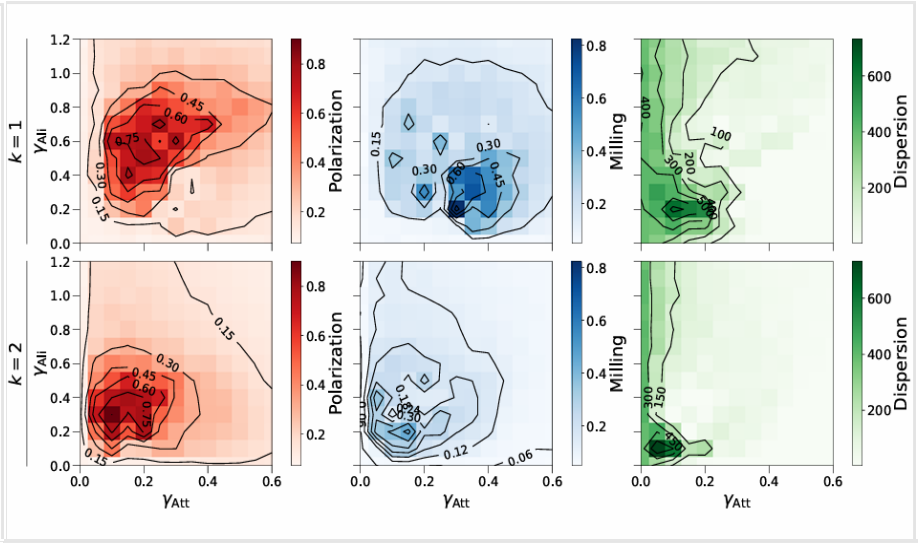
- N_ω= 1 (single decision)
  - High instability -> fragmentation
- N_ω = 2-16
  - Control is frequent enough to stabilize but not to frequent
- N_ω > 16
  - Too frequent updates -> milling replaces polarization

Results (extended model)

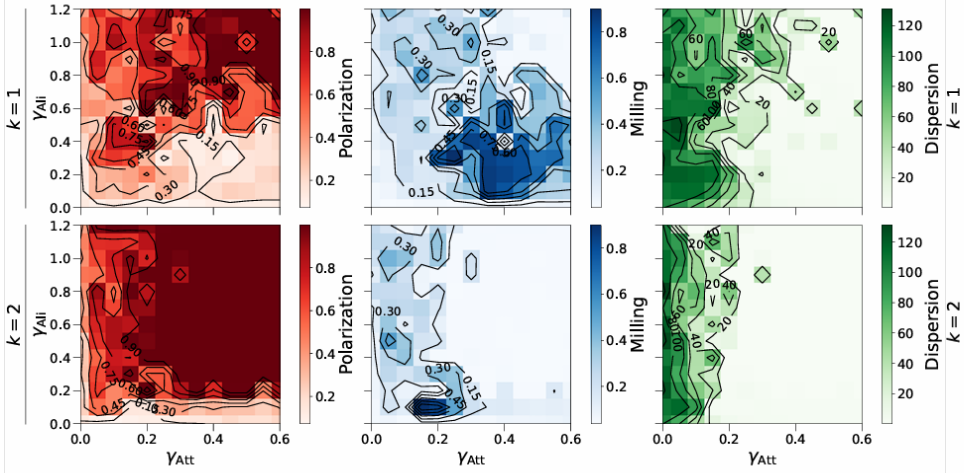
$\omega = 0, n_\omega = 1$



$\omega = 0.5, n_\omega = 1$



$\omega = 0, n_\omega = 10$



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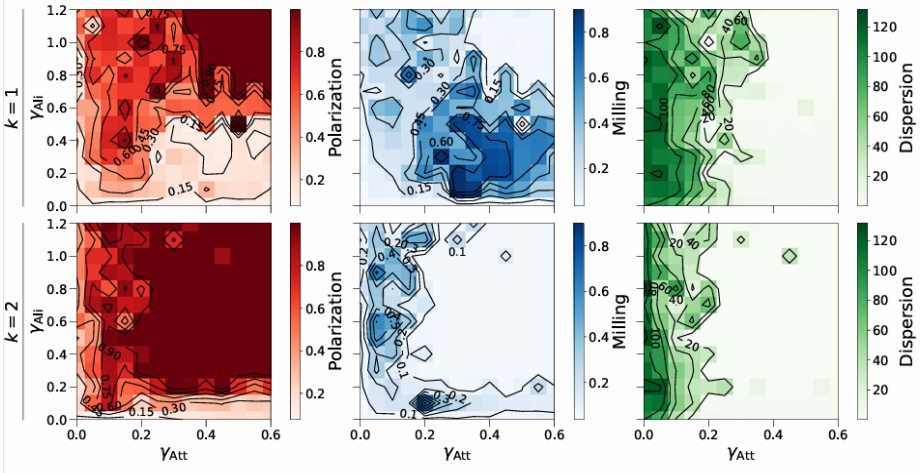
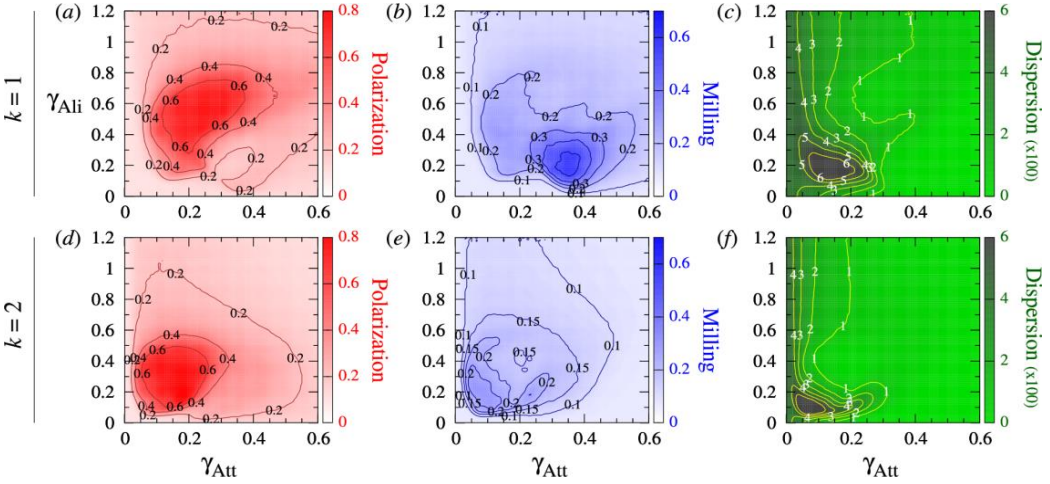
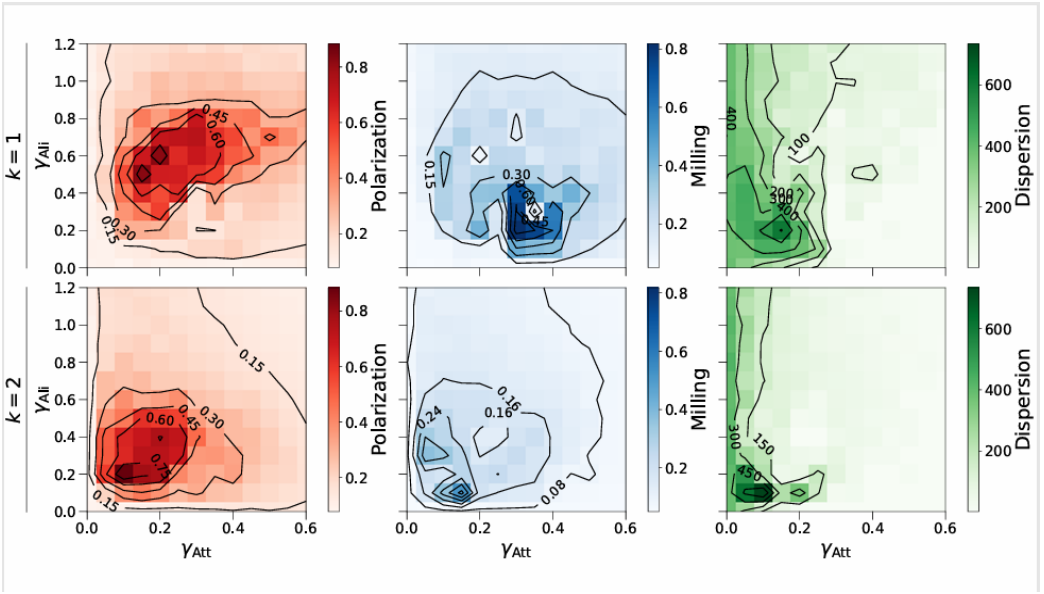


Extended results

- Base vs extended
- Confirmed with base model
- Increasing duty cycle improves cohesion but weakens precise alignment because inertia amplifies small heading differences
- Polarization peaks at intermediate decision resolution because too little control causes fragmentation, while too much control allows rotational modes to emerge and compete with alignment.





$\omega = 0, n_\omega = 1$

Conclusion & discussion

- Successfully re-implemented and extended a burst-and-coast model
- Key findings:
  - Intermediate duty cycles favor stable schooling
  - Intra-burst decisions are critical; a single decision might be insufficient for cohesion
- Biggest challenges:
  - Confirming if our results are correct
  - Lots of compute power needed
- Future work:
  - More realistic implementation:
    - Heterogeneity in speed, reaction time, noise
    - Global decision making, environmental interactions
  - More runs, bigger parameter sweep, larger simulations,… (just more compute power & time)