Evaluating Shepherding Algorithms Using Flock Properties

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Motivation & Research Question

- Shepherding is a classic collective behavior problem
- Efficiency requires both movement and cohesion
- We expand on the proposed model, making it more realistic

The Original Paper

- Starting point - *Collective responses of flocking sheep (Ovis aries) to a herding dog (border collie)* (Jadhav et al.)
- Implemented their model in code
- Expanded on their model by adding fatigue to movement

The Model - Sheep

The sheep's drives:

Always:

- repulsion from the other sheep
- random noise

When dog is nearby:

- attraction to the center of neighbors
- alignment of the velocity direction
- repulsion from the dog

The Model - Dog

The dog's modes of operation:

Collecting: herd is *not* cohesive

- moves to collect stray sheep

Driving: herd is cohesive

- the dog moves behind the herd to push it forward

Our Contribution: Fatigue

- We extend the Jadhav shepherding model by adding an internal fatigue state to each agent
- Fatigue is modeled using a three-compartment controller (3CC): resting, active, and fatigued capacity
- Task demand (dog proximity and local crowding) determines muscle activation
- Fatigue accumulates during sustained movement and recovers over time
- Fatigue affects only movement speed, not directional decision-making

Task Load - Sheep

Task load $TL_i^n \in [0,1]$ represents the locomotor demand on agent i at time n and acts as the input to the fatigue model.

Sheep task load:

$$TL_i^n = \min\left(1,\ TL_{i,\mathrm{dog}}^n + TL_{i,\mathrm{soc}}^n\right)$$

Dog-induced demand:

$$TL_{i,\mathrm{dog}}^n = \begin{cases} 0, & d_{iD}^n \geq R_D \\ TL_{\max}^{\mathrm{dog}}\left(1 - \dfrac{d_{iD}^n}{R_D}\right), & d_{iD}^n < R_D \end{cases}$$

Sheep-to-sheep proximity demand:

$$TL_{i,\mathrm{soc}}^n = \begin{cases} 0, & d_{i,\min}^n \geq d_{\mathrm{rep}} \\ TL_{\max}^{\mathrm{soc}}\left(1 - \dfrac{d_{i,\min}^n}{d_{\mathrm{rep}}}\right), & d_{i,\min}^n < d_{\mathrm{rep}} \end{cases}$$

Task Load - Dog

Task load $TL_i^n \in [0, 1]$ represents the locomotor demand on agent i at time n and acts as the input to the fatigue model.

Dog task load (mode-dependent):

$$TL_D^n = \begin{cases} TL_{\text{gather}}, & \text{collecting a stray} \\ TL_{\text{drive}}\left(\dfrac{v_B^n}{v_{D,\max}}\right), & \text{driving the flock} \\ 0, & \text{idle} \end{cases}$$

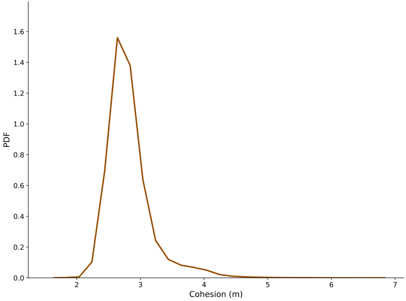
- Dog task load depends on behavioral mode rather than distance, reflecting different energetic demands of collecting and driving.

Simulation

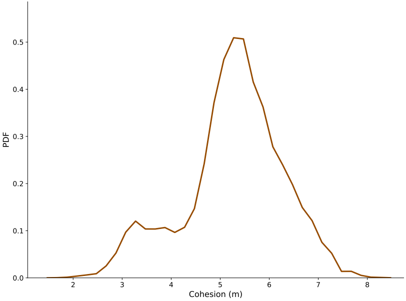
Comparison of flock dynamics under different algorithms

Play Simulation

Results: Cohesion



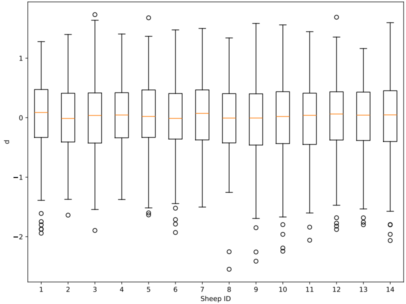
(a) Original model



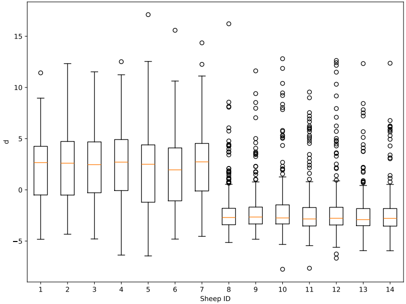
(b) Fatigue-augmented model

Figure: Probability density of flock cohesion.

Results: Relative Spatial Position



(a) Original model



(b) Fatigue-augmented model

Figure: Average relative spatial position of sheep within the flock.

Discussion & Conclusions

- Sheep herding - unwilling movement of agents
  - also gives insights into predator-prey dynamics
- Comparing models and sheep attributes on measurable properties
- Models with same interaction rules can vary in properties
- Energy models are normally applied mostly to population simulation models
- Research might be useful for other applications

Thank You

Thank you for listening!

References

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