What information must individuals perceive for cohesive cooperative transport?

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Introduction

Ant colonies consist of autonomous workers that coordinate their actions to perform complex tasks. Cooperative transport – working together to move an enormous object – is a coordinated task for which ant species exhibit extreme variation in efficiency. Weaver ants carry dead birds and lizards vertically up tree trunks [1], while many species fail at coordinated transport [2, 3].

Paratrechina longicornis

How does a group of ants converge on a single travel direction? We might expect workers in an ant colony to agree on where to take an object (the nest), but deadlocks are common [2]. Deadlocks – when workers try to move the object in opposing directions –can last hours in inefficient species [3]. Shorter deadlocks occur in efficient species at the start of a transport effort [4], and when there are multiple routes to the nest. Being capable of breaking a deadlock separates the good transporters from the bad. **We explore whether a simple model can reproduce the deadlock-breaking observed in efficient species.**

Approach

We developed a one-dimensional **mean-field model** to explore deadlock-breaking in cooperative transport. We asked **what is the minimum information that workers must gather to converge on one travel direction?** Further, we evaluated the effect of persistence, a behavioral parameter. Highly persistent ants try to move the object in the same direction endlessly without success. We asked **does individual persistence increase or decrease convergence?**


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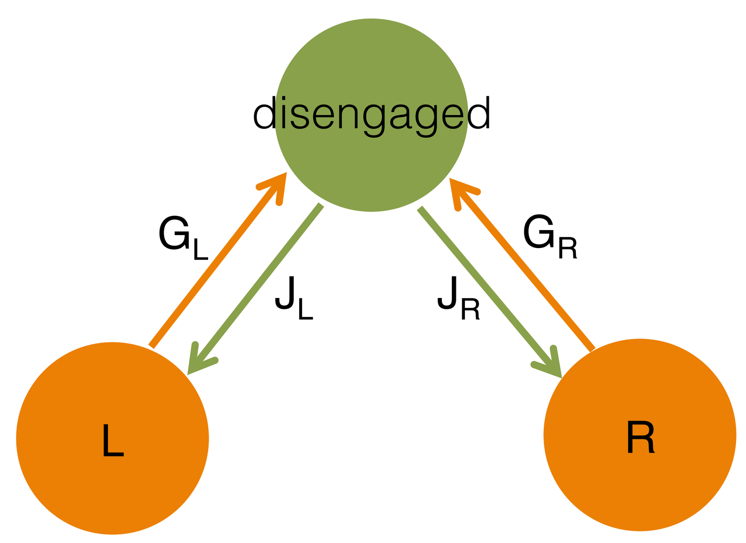
Model



$$\frac{dN_L}{dt} = J_L N_D(t) - N_L(t) G_L$$

$$\frac{dN_R}{dt} = J_R N_D(t) - N_R(t) G_R$$

$$\frac{dN_D}{dt} = N_L(t) G_L + N_R(t) G_R - (J_R + J_L) N_D(t)$$

The model incorporates three behavioral states: move left, move right, and disengaged. The number of individuals in each state are, respectively, N_L, N_R, and N_D. Ants shift from an active state to disengaged by "giving up," and from disengaged to an active state by "joining." If the joining rates (J_L and J_R) differ, individuals have a shared directional bias. The giving-up rates, G_L and G_R follow one of three paradigms depending on the information available:

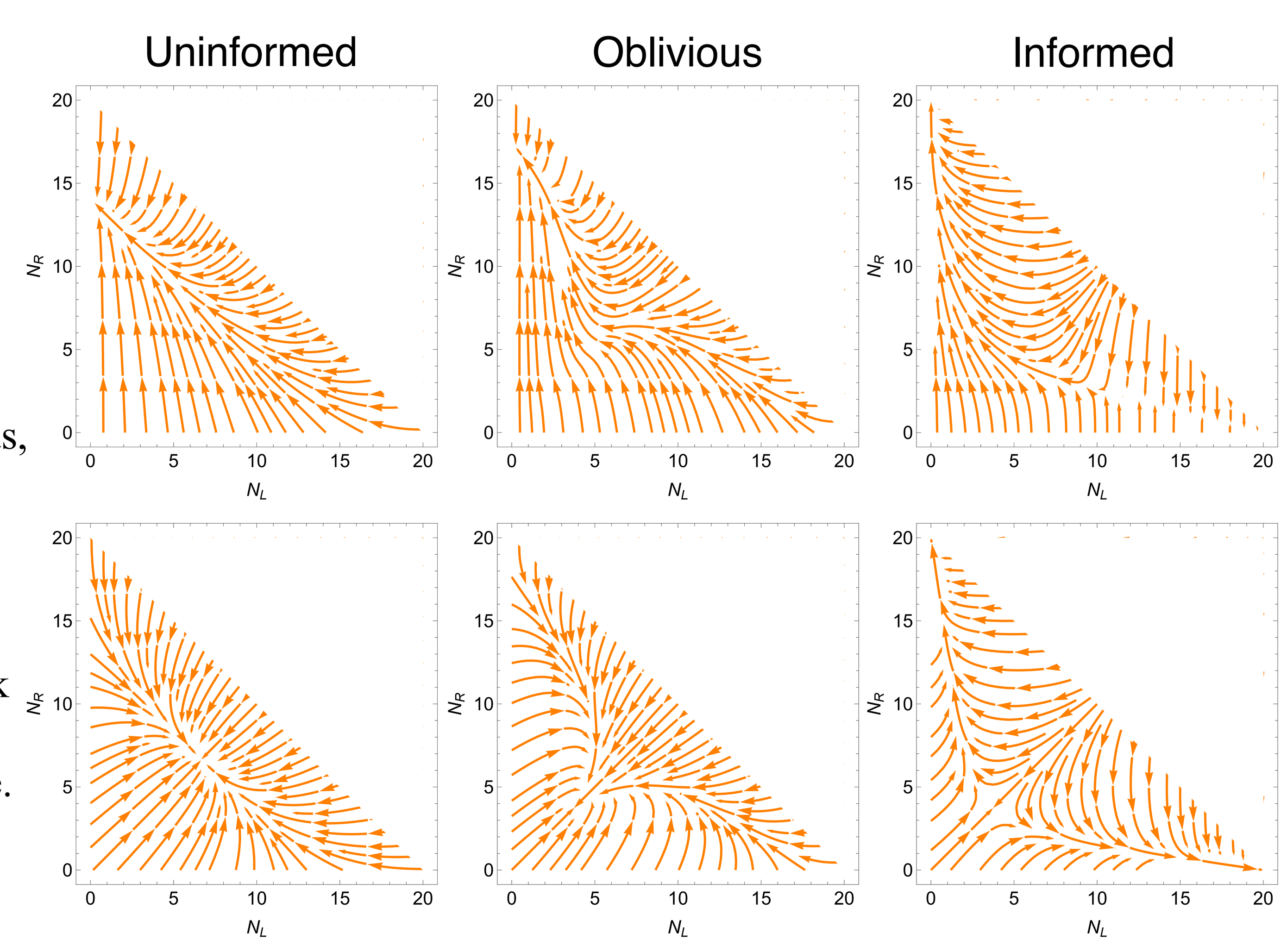
1. **Uninformed**: no information available. $G_L = G_R$ = constant.
2. **Oblivious**: G is high when $|N_L - N_R|$ is small and low when $|N_L - N_R|$ is large. Ants give up rarely when the transport is successful (one side clearly winning), even if they are on the losing side.
3. **Informed**: Ants know if the transport is "successful" and if they are on the winning side or not. When $N_L - N_R$ is high, ants give up rarely if they are in the "move left" state and frequently if they are in the "move right" state.

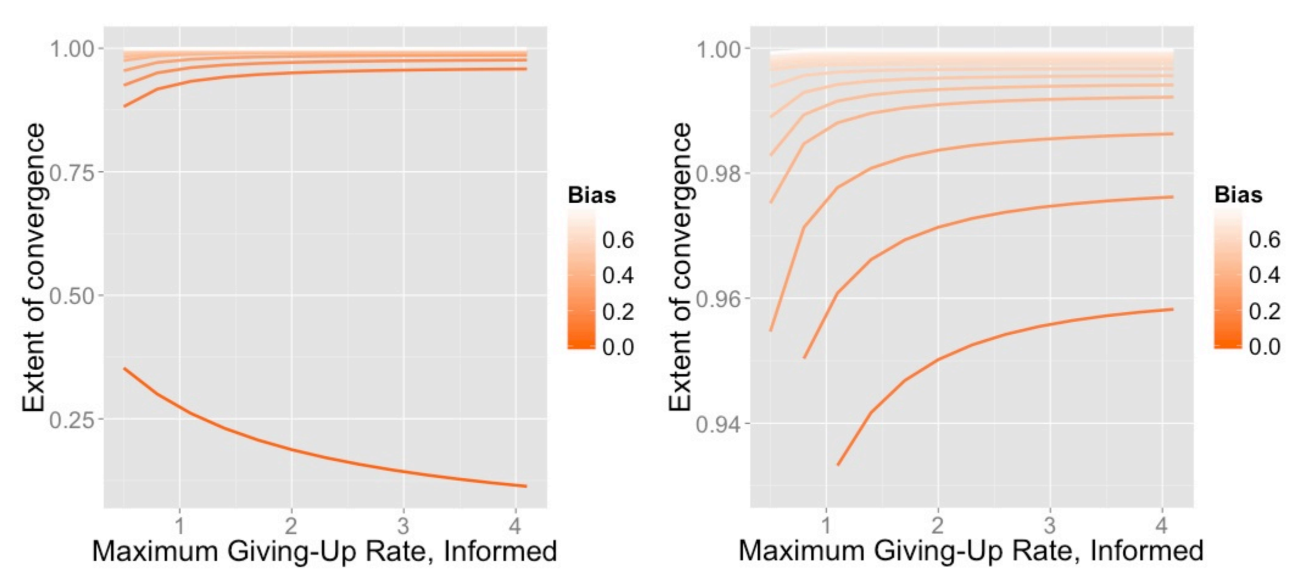
We numerically solved the system of differential equations under many sets of parameter values keeping track of the number of individuals in each behavioral state. We queried the results for extent of convergence. Important parameters include persistence, which is the inverse of the maximum G.

Results

Top row: Directional bias in favor of N_R. Regardless of giving-up paradigm, a shared bias in joining direction was sufficient for ants to converge on that direction.

Bottom row: No directional bias. **Right**: uninformed, **middle**: oblivious, **left**: informed. Each paradigm shows a deadlocked equilibrium. For uninformed and oblivious paradigms this deadlock is stable, perturbations away from equilibrium will lead back to a deadlock. For the informed paradigm, the equilibrium is unstable. Perturbations away from equilibrium lead to convergence.





Persistence interacts with directional bias in the informed paradigm. First panel: when there is no bias, persistence (low max giving-up rate) increases convergence. Persistence lowers convergence with non-zero bias, and the effect is stronger for a smaller bias. Second panel is the same as first panel but zoomed in on upper portion.

Conclusions

The primary conclusions of our model are:

1. **Global directional cues are sufficient** for a group to engage in coordinated transport.
2. Without directional cues, cooperative transport is successful if individuals give up when they are moving against the prevailing direction. In other words, **individuals must give up when they are fighting a losing battle.**
3. Persistence also affects transport efficiency, but the effect depends on the available information.

We do not contend that the these conditions are the only ones that could lead to successful transport. In nature, ants may have other sources of information or different rules for coordination. But we show here that a simple model reproduces a critical feature of efficient cooperative transport. Minimal information is sufficient for ants to converge on a direction. This finding informs future field and modeling studies.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Future Directions

We are extending this model to a stochastic, agent-based context with two spatial dimensions. This will allow us to more closely examine how stochasticity affects the system and to see if our conclusions are valid in a context more similar to natural cooperative transport in ants. These models complement field experiments investigating deadlocks in ant species of varying efficiency.

Literature cited

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