Dynamics of Social Interactions and Agent Spreading in Ant Colonies: Effects of Environmental Events and Spatial Heterogeneity

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The relationship between division of labor and worker spatial behavior in social insect colonies provides a useful context to study the ways in which social interactions influence the spread of agent (which could be information or virus) across distributed agent systems. In colonies, as complex adaptive systems, inter-individual interactions at local scales influence agent transmission or inhibition at global scales. Spatial heterogeneity associated with variation in individual task roles influences social contacts, and thus the way in which agent moves through social networks. When individuals within a specific task interact more, this has the potential to rapidly spread agent within that group, but can also inhibit transmission of agent between task groups. We use variation in movement patterns associated with different tasks to build and study an agent based model of information flow. The model incorporated: 1) three task groups, each assigned a general spatial zone in which the task is preferentially conducted; 2) variation in initial distributions of individuals, from general (random) mixing to aggregated; 3) variation in space use with task role, modeled as a random walk, or via bias in turning radius towards the task zone. These components generated a strong linear relationship between the degree of spatial heterogeneity and social contacts, with correspondingly higher social contact rates and larger spatial heterogeneity degree (SHD). As spatial fidelity increased, between-group average contact rate tended also to increase, while within-group average contacts decreased. Finally, the spreading dynamics of agents followed a modified nonlinear logistic growth, with different spreading speeds for different initial colony environments. More specifically, a higher spatial fidelity generated higher SHD and spreading speed when initial spatial distributions were random. In contrast, they decreased under initial conditions of aggregated distributions. These results show that flexibility in spatial fidelity patterns, which are often driven biologically via differences in behavioral performance, can have both inhibiting and facilitating effects on agent transmission rate. Our model reveals the potential functions of flexible spatial behavior and deepens our understanding of how ant colonies balance the transmission of agents with different behavioral attributes under varied environmental conditions.