Phase Transition in Ant Colonies

Two types of ant colonies—one that experiences sudden bursts of activity and one that doesn't—exemplify two distinct phases of collective behavior.

By **Samuel Jarman**

Through simulations, researchers have discovered the difference between ant colonies where colony-wide activity occurs in sudden bursts and those where it doesn't. By simulating the motions of ants using experimentally measured quantities as inputs, the team showed that switching from one state to the other can be modeled as a phase transition controlled by parameters such as the speed with which ants travel [**1**]. If these principles hold up in ant observations, they could help biologists better understand the complex dynamics of ant colonies.

From harmonious movements in schools of fish to bursts of electrical signals in the brain, synchronization can emerge across a vast array of systems in nature. For acorn ants, individuals move largely independently, cycling through periods of activity (where they can move through the colony) and inactivity (where they stay in one location). But at seemingly random intervals, these cycles will suddenly synchronize across the colony, creating a burst of activity where a large fraction of ants move simultaneously. Once triggered, this burst spreads through the colony almost instantly.

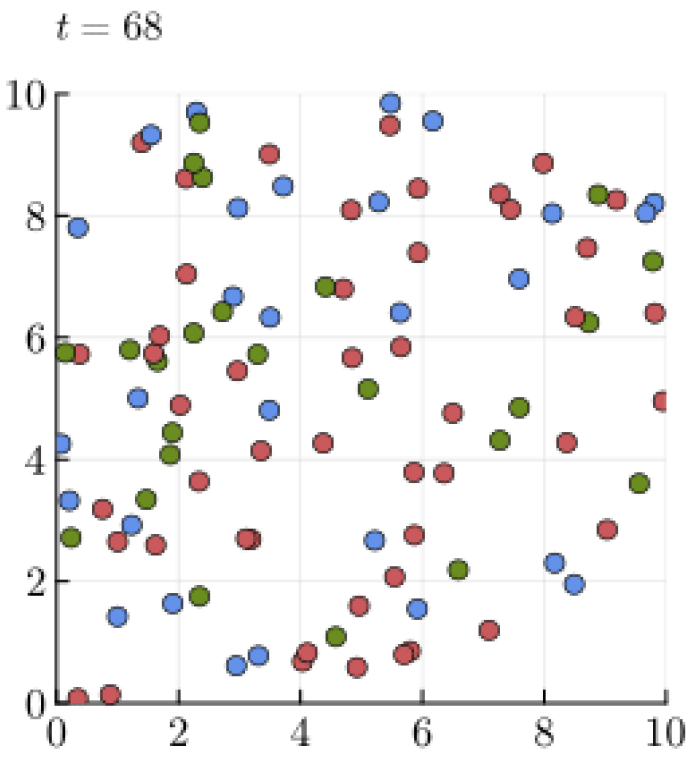
Unfazed. Ants in a nest can exhibit sudden, colony-wide bursts of activity.
Credit: comenoch/stock.adobe.com

Previous simulations have suggested that these bursts emerge through social interactions between ants: If an ant in the active part of its cycle interacts with one in its inactive state, the second ant can become activated. Like the spread of a contagion, the signal to activate can spread around the colony.

Yet according to Maurizio Porfiri of New York University, these earlier models weren't sufficiently realistic. For example, in some earlier models, a single parameter represented the probability that an ant would become activated by another ant. But these models did not account for the fact that this activation requires the two ants to encounter one another as they move about the nest.

Porfiri and his colleagues wanted a model where interactions between ants could emerge naturally, based on their simulated movements. These motions would be derived directly from experimentally measured behaviors and properties of ants in nests, such as their speeds, densities, and the distance over which they can sense a neighbor.

The team's model predicted colony-wide bursts of activity, but only under the right conditions. If ants in their active state moved below a certain speed or were not close enough to their nest mates, the signal to activate couldn't spread through the colony fast enough to maintain the typical cadence of the bursts. But above that speed or density threshold, ants encountered their neighbors often enough to keep the bursts going.



In this simulation, an activation signal from a "first-mover" ant rapidly triggers the whole colony to start moving. Ants can be in one of three states: active (moving; red), inactive (stationary; blue), and refractory (stationary and temporarily incapable of being activated; green).
Credit: M. Napoli *et al.* [1]

According to the researchers, the colony's behavior at the speed threshold can be viewed as a phase transition, directly comparable to the sudden state changes seen in physical systems. Instead of temperature, the frequency of the ants' interactions determines the phase. The position of this phase boundary is influenced by the ants' speed, the density of ants in the nest, and the radius within which ants can sense one another.

Through further analysis of their model, the researchers showed that bursts are initiated by just a single ant, which they dubbed the "first mover." Once its signal is initiated, much of the colony becomes active almost instantaneously. "Notably, synchronization does not depend on any specific individual; any ant can serve as the first mover," says team member Simon Garnier from the New Jersey Institute of Technology.

Porfiri and his colleagues compared their model's predictions with previously published measurements of ant colonies and found a close match with the timing and scale of activity bursts. In future work, the model could provide rich new ground for multidisciplinary experiments, Porfiri says. "By viewing synchronization as a phase transition, experimentalists may determine the regime [phase] in which ant colonies of a given species operate."

Guy Theraulaz of the University of Toulouse in France, an expert in collective behaviors in animal groups, is impressed. "This paper brings together three ingredients that had often been treated separately," he says. Those ingredients are the movement of ants within the nest, activation dependent on the proximity of inactive to active ants, and transitions between behavioral states. "[The] most exciting future challenge will be to test experimentally whether real colonies indeed operate near the predicted transition boundary and whether doing so enhances their adaptability and efficiency."

Samuel Jarman is a science writer based in the UK.

REFERENCES

1. M. Napoli *et al.*, "Nest-level phase transition drives synchronized activity bursts in ant colonies," **PRX Life 4, 033010 (2026).**