Control without hierarchy

Understanding how particular natural systems operate without central control will reveal whether such systems share general properties.

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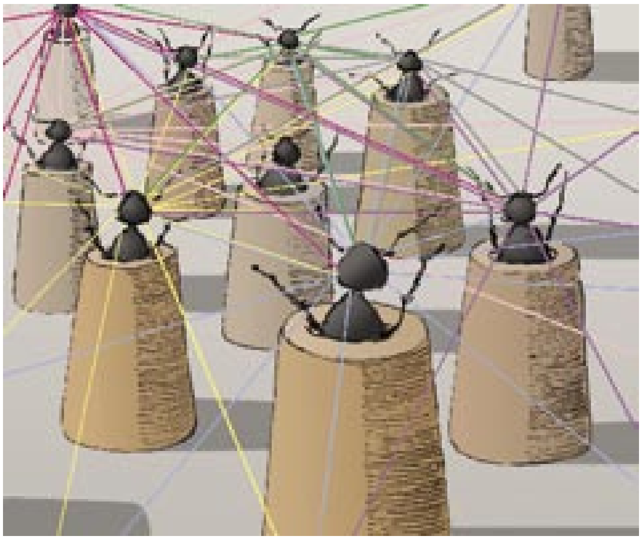
Because most of the dynamic systems that we design, from machines to governments, are based on hierarchical control, it is difficult to imagine a system in which the parts use only local information and the whole thing directs itself. To explain how biological systems operate without central control — embryos, brains and social-insect colonies are familiar examples — we often fall back on metaphors from our own products, such as blueprints and programmes. But these metaphors don't correspond to the way a living system works, with parts linked in regulatory networks that respond to environment and context.

Recently, ideas about complexity, self-organization, and emergence — when the whole is greater than the sum of its parts — have come into fashion as alternatives for metaphors of control. But such explanations offer only smoke and mirrors, functioning merely to provide names for what we can't explain; they elicit for me the same dissatisfaction I feel when a physicist says that a particle's behaviour is caused by the equivalence of two terms in an equation. Perhaps there can be a general theory of complex systems, but it is clear we don't have one yet.

A better route to understanding the dynamics of apparently self-organizing systems is to focus on the details of specific systems. This will reveal whether there are general laws. I study seed-eating ant colonies in the southwestern United States. In each ant colony, the queen is merely an egg-layer, not an authority figure, and no ant directs the behaviour of others. Thus the coordinated behaviour of colonies arises from the ways that workers use local information.

If you were the chief executive of an ant colony, you would never let it forage in the way that harvester ant colonies do. Put down a pile of delicious mixed bird-seed, right next to a foraging trail, and the ants will walk right over it on their way to search for buried shreds of seeds 10 metres further on. This behaviour makes sense only as the outcome of the network of interactions that regulates foraging behaviour.



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Foraging begins early in the morning when a small group of patrollers leave the nest mound, meander around the foraging area and eventually return to the nest. A high rate of interactions with returning patrollers is what gets the foragers going, and through chemical signals the patrollers determine the foragers' direction of travel. Foragers tend to leave in the direction that the patrollers return from; if a patroller can leave and return safely, without getting blown away by heavy wind or eaten by a horned lizard, then so can a forager.

Once foraging begins, the number of ants that are out foraging at any time is regulated by how quickly foragers come back with seeds. Each forager travels away from the nest with a stream of other foragers, then leaves the trail to search for food. When it finds a seed, it brings it directly back to the nest. The duration of a foraging trip depends largely on how long the forager has to search before it finds food. So the rate at which foragers bring food back to the nest is related to the availability of food that day. Foragers returning from successful trips stimulate others to leave the nest in search of food.

But why do foragers walk right past seed baits? We learned recently that during a day, each forager keeps returning to the same patch to search for seeds. Once a forager's destination for the day is set, apparently by the first find of the day, even a small mountain of seeds is not enough to change it. In this system, the success of a forager in one place, returning quickly to the nest with a seed, stimulates another forager to travel to a different place. A good day for foraging in one place usually means a good day everywhere; for example, the morning after a heavy rain, seeds buried in the soil are exposed and can be found quickly.

The regulation of foraging in harvester ants does not use recruitment, in which some individuals lead others to a place with abundant food. Instead, without requiring any ant to assess anything or direct others, a decentralized system of interactions rapidly tunes the numbers foraging to current food availability.

It is difficult to resist the idea that general principles underlie non-hierarchical systems, such as ant colonies and brains. And because organizations without hierarchy are unfamiliar, broad analogies between systems are reassuring. But the hope that general principles will explain the regulation of all the diverse complex dynamical systems that we find in nature, can lead to ignoring anything that doesn't fit a pre-existing model.

When we learn more about the specifics of such systems, we will see where analogies between them are useful and where they break down. An ant colony can be compared to a neural network, but how do colonies and brains, both using interactions among parts that respond only to local stimuli, each solve their own distinct set of problems?

Life in all its forms is messy, surprising and complicated. Rather than look for perfect efficiency, or for another example of the same process observed elsewhere, we should ask how each system manages to work well enough, most of the time, that embryos become recognizable organisms, brains learn and remember, and ants cover the planet. ■

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FURTHER READING

Gordon, D. M. *Ants at Work* (W. W. Norton and Co., New York, 2000).
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Lewontin, R. C. *The Triple Helix: Gene, Organism and Environment* (Harvard Univ. Press, Cambridge, 2000).

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