Collective genius

Working together enables tiny ants to do very clever things, and it could teach us better maths and robotics, finds Peter Hess

BARRO Colorado Island is tiny and sits in the middle of the Panama Canal. Here, below the forest dome, a diminutive predator scuttles over dead leaves and along narrow branches. Nearly blind, this *Eciton* army ant follows a trail of chemical signals laid down by her sisters. She pushes forward, relentlessly, in search of prey. Whatever she finds, she'll bring back to the nest to share with her colony.

But then she stops. The ground has dropped away in front of her. There is no scent trail, just empty space. Other members of the colony that were following begin to climb over her. Now, instead of walking in a line, they grip hold of one another using hooks on their feet, adding body after body to build an impromptu bridge. More and more join in, until they traverse the gap. And there they remain until the entire foraging party, numbering hundreds, has crossed. Then, as suddenly as it came into being, the bridge disperses, and the ants continue on their way.

How do these creatures achieve such an impressive feat of coordination with very limited brainpower and no overview of the situation? That's the question a group of researchers working on Barro Colorado Island set out to answer. Their efforts have revealed how ants use simple cues to organise themselves into complex living structures. It's a wonder of nature, and it could offer insights for engineers, mathematicians and robot designers. What's more, it might even shed some light on our own interactions. ›

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Master builders: ants possess remarkable construction abilities

Eciton army ants are not the most obliging research subjects. "They bite and sting at the same time, which is fun," says Matthew Lutz of Princeton University. But that's not the biggest problem. They are also nomadic, so you can't keep them in one of those plastic ant farms you may have had in your school science lab. "The main challenge is to bring the lab to the ants because you can't bring the ants to the lab," says Simon Garnier of the New Jersey Institute of Technology in Newark. That is exactly what he, Lutz and their colleagues did.

Each day, an *Eciton* army ant colony builds a temporary home, or bivouac, which can be hundreds of metres from the previous day's site – so wherever the ants were yesterday is probably not where they will be today. After locating the new territory, the team blocked the foraging path using a V-shaped obstacle on its side, with the long edge in front of the ants. This forced the ants to take a diversion – first left, then right – or to form a bridge over the gap created by the mouth of the V. Then the researchers adjusted the construction to narrow or widen the gap, and watched to see how the ants would react.

They found that the ants did build bridges to create a shortcut, rather than going the long way around. However, these bridges did not take the shortest possible route. Instead, the ants created dynamic structures that started near the apex of the V and then moved towards its mouth, becoming longer and wider but rarely creating a straight path. Why would they do that? The researchers suspected the ants were making a cost-benefit trade-off. "If they put too many individuals into the bridges, it'll impact foraging activities," says Garnier. It appears that on a moment-to-moment basis, they make collective, instinctive decisions about how the group should best allocate labour between bridge-building and foraging. That's quite a feat, given that each ant has little awareness of the broader context of its actions. All they have to guide them are local knowledge and their senses. (See a video of ants building bridges in the online version of this article at bit.ly/issue3090.)

"How do ants achieve such feats with very little brainpower and no overview of the situation?"

Coordination is not by sight or smell but by detecting the forces produced by other ants

Being part of a bridge may not be as demanding for an individual ant as it might seem

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Yet *Eciton* army ants build more than just bridges. When walking along a vertical surface, such as a wall, individuals will stop and hold themselves against it. "Over time, that builds up to create a safety net or scaffolding so other ants will be caught if they fall," says Lutz. He suspects this behaviour follows the same simple rules as bridge-building. "It doesn't make sense for them to have some kind of different mechanism for each of these things," he says.

So how do they do it? The team's field experiments suggest that the guiding force is the degree of contact between each ant and other members of its group. When traffic flow becomes interrupted, bodies pile up, and this increases the chance that an ant will stop and become part of a structure. If traffic intensifies, more ants add their bodies to the bridge to increase its capacity. Eventually, the jam clears up, decreasing contact and increasing the likelihood that an ant in the structure will unhook from the others and continue along the foraging path. Using this simple mechanism, the ants continuously modify the length, width and position of their bridges.

What's more, when the researchers made a computer model to work out what construction would give the best cost-benefit trade-off, they found that it matched the dynamic bridges they had observed. In other words, the colony is able to effectively manage its resources, allocating enough bodies to building while at the same time maximising

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the amount of foraging it can achieve.

A similar mechanism is probably used by other ant species to coordinate their collective behaviour. Think of the classic image of a group of ants carrying absurdly oversized prey. Like bridge-building, the awkward endeavour is made possible by dynamic adaptations. “By exerting forces on the load and detecting counterforces, each ant can use that to adapt its own behaviour,” says Stephen Pratt of Arizona State University in Tempe, who has studied the behaviour in *Aphaenogaster* ants. They are not watching or smelling each other. “They’re using the load itself as a nexus to guide behaviour.”

Such cooperation is impressive, but it is also a conundrum. Surely it is in each individual’s best interests to let the others work together and then simply take the benefits? Why would an army ant become a building block in a bridge when it could just cross the bridge made by others?

Lutz suggests one possibility: being part of a bridge is easier than foraging. He suspects that as soon as an ant joins the construction, it goes into a low-energy state and simply hangs there by its hooks. A forager, on the other hand, risks her life killing prey.

But there is a more fundamental reason for cooperation among colonial insects: they are not really in competition with one another. In evolutionary terms, competition comes down to producing more offspring, but ants in a colony are closely related sisters and only one, the queen, reproduces. “An ant is not in a position to make profit on its own,” says Deborah Gordon at Stanford University in California, who studies harvester ants. She likens it to a cell in a single organism.

But there is one key difference, in that the colony’s intelligence is distributed among its component parts. That makes it a “superorganism” capable of unique behaviour and adaptations that individual ants cannot achieve. Such activities are classic examples of “emergent” behaviour – group-level action that is more sophisticated than the sum of its parts. And that makes ant building more than a mere natural curiosity.

Colonial robots

Such behaviour is the inspiration for swarm-intelligence researchers seeking to program phalanxes of relatively simple robots that are both autonomous and cooperative. The big challenge is coordination. Instead of having a central processing unit, the robots interact at the local level in response to local conditions. “Swarm-based robotics has introduced a new kind of distributed control very similar to the one used by social insects,” says Guy Theraulaz at Paul Sabatier University in Toulouse, France. These swarm robots can work alone or in conjunction with many others. They have many potential uses, from finding cracks in high-rise buildings to performing search-and-rescue operations in dangerous environments.

So far, these ideas haven’t been realised. One of the most sophisticated swarms to date has been created by the Self-organizing Systems Research Group at Harvard University. It consists of 1000 small, inexpensive robots that use local-level interactions to assemble themselves into two-dimensional shapes. They are not exactly the capable, versatile, autonomous machines that roboticists dream of – but it’s early days.

Some people believe we can cash in on collective intelligence without the need for robots. “Don’t look at ants as little robots we want to build,” says Ted Pavlic at Arizona State University. Instead, he says, we should ask what sorts of problem the colony solves.

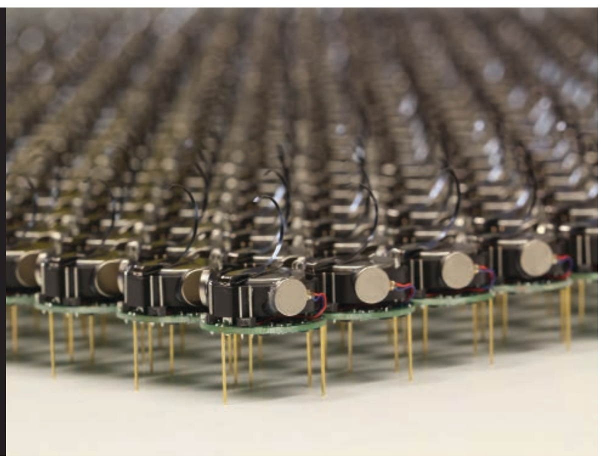
For example, when ant colonies are given multiple different food sources with varying nutrient contents, they always forage what the colony needs. In effect, says Pavlic, they are solving multivariable maths equations: if they allocate more foragers to one food source, they have fewer to allocate to others.

“We have models with the exact same mathematics, like managing power on a smart grid,” he says. We manage such systems centrally, making conscious calculations of costs and benefits, whereas the colony manages without central control. “Working out how ants do this teaches us new things about the essence of the problems,” he says. “Ants are not just automatons following basic rules. They have properties that really blow your mind.”

Getting to grips with how ants team up to complete tasks could have many applications in engineering. However, a bigger potential prize lies in working out how the colony’s intelligence is greater than the sum of its parts.

Such emergent behaviour occurs in complex human systems including stock markets, democracies and even our brains. Our intelligence, for example, can be viewed as an emergent property of a huge colony of neurons in our head. That means ant antics could give us insights into our own activities. “A lot of things in human society are based on self-organising principles,” says Garnier. “The same principles that organise ant colonies organise human behaviour.” ■

“Swarm robots use a kind of distributed intelligence very similar to that of social insects”



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