Shape-shifting worm blob model could inspire future robot swarms

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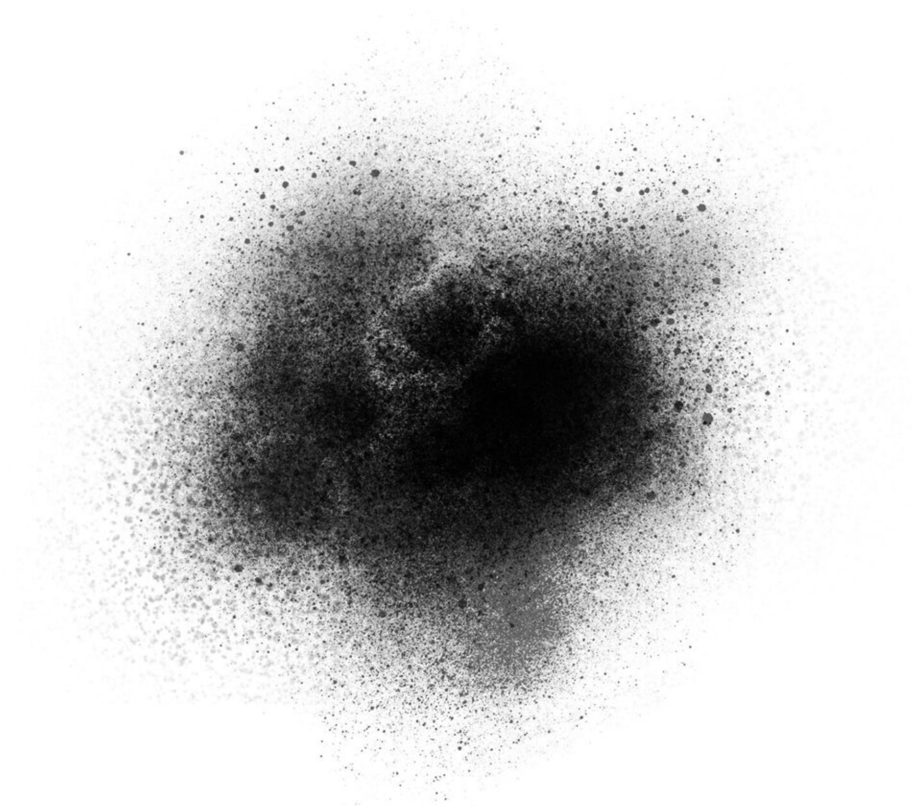

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Blackworms (Lumbriculus variegatus) are distant relatives of rainworms, measuring up to 10 cm long. They live in shallow marshes, ponds, and swamps in Europe and North America, where they feed on microorganisms and debris. To protect themselves from drought, blackworms can aggregate as entangled, shape-shifting "blobs" composed of a few to hundreds of individuals. Just like swarms of bees, rafts of fire ants, or flocks of starlings, blackworm blobs can show "intelligent" collective movement.

Now, scientists show that effective collective movement can only emerge in blackworm blobs when conditions are just right—in particular, when there is a balance between the activity and "clinginess" of individual blackworms. They recently published their results as open access in the journal *Frontiers in Physics.*

"While individual worms within the blob must cling to each other, they also need to be accessible to the outside to keep receiving information from the wider environment," said first author Dr. Chantal Nguyen, a postdoctoral researcher at the BioFrontiers Institute of the University of Colorado in Boulder, US.

"What is the best balance between these opposing requirements, which would allow the worms an optimal level of sensing and responding to the environment as a single whole? To find this balance, we did a set of experiments on real blackworms to create a realistic model of a worm blob."

Finding the right temperature

Why are worm blobs important to study? The reason lies precisely in their social organization across multiple levels.

Interactions between individual blackworms can yield unexpected, novel properties when they move as a blob. Such "emergent" properties are a feature of biological systems, from proteins to multicellular organisms to ecosystems. Therefore, blobs aren't only fascinating in their own right, but can also serve as a model for similar systems too small or too large to easily observe, for example the semi-flexible actin filaments in the cytoskeleton, cilia, and flagella of cells.

"Active biopolymers and actin filaments are great examples of so-called 'entangled active matter collectives,' which are a hot topic in robotics and materials science," said co-author Dr. M. Saad Bhamla, an assistant professor at the Georgia Institute of Technology, in Atlanta, US.

To study the response of blackworms to environmental changes, Nguyen and other researchers recorded the movement of individual blackworms in water baths whose temperature gradually increased from 12 to 34 ºC. Up to 30 ºC, the worms tended to explore the bath, seeking its walls and then moving along them. At higher temperatures, damaging to their physiology, worms mostly stayed still.

Testing a digital worm blob

The researchers then simulated the individual and collective behavior of blackworms in a computer model, restricting blobs to just two dimensions for simplicity. They programmed the worms to behave like molecules: repelling versus attracting each other at very close distances versus moderate distances, and not interacting at greater distances. Isolated worms were programmed to explore more so at low temperatures. The flexibility between their body segments was set to moderate, resulting in the model worms stretching out at low temperatures but coiling up at higher temperatures.

The researchers show that sustained collective movement of blackworm blobs can only emerge when there is a fine balance between the "clinginess" of the worms and their individual movement, so that the blobs stay together as they move to seek out colder spots. Around this optimal balance, model blobs moved at a speed of 1 mm/s on average, but more slowly for larger blobs.

"When we changed the parameters, especially the attraction between worms and the strength of individual self-propulsion, we observed three broad behavioral states: One where collective locomotion consistently occurs, another where blobs fall apart, and finally one where worms cling so strongly to each other that blobs cannot move," said coauthor Dr. Orit Peleg, an assistant professor of computer science at the BioFrontiers Institute.

"Real blackworms show these as well, which means that our model—despite its simplicity—captures much of the complexity of the real organism."

"We hope that our present results can be applied to the design of novel robotic systems where individual soft and flexible robots can entangle and move as a unit. Another possible application would be in 'engineered living materials,' such as building materials or fabrics, which are composed of autonomous units that can reorganize themselves for repair or to respond to the environment," concluded Bhamla.

More information: Chantal Nguyen et al, Emergent Collective Locomotion in an Active Polymer Model of Entangled Worm Blobs, *Frontiers in Physics* (2021). DOI: 10.3389/fphy.2021.734499

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