Simple robots, smart algorithms

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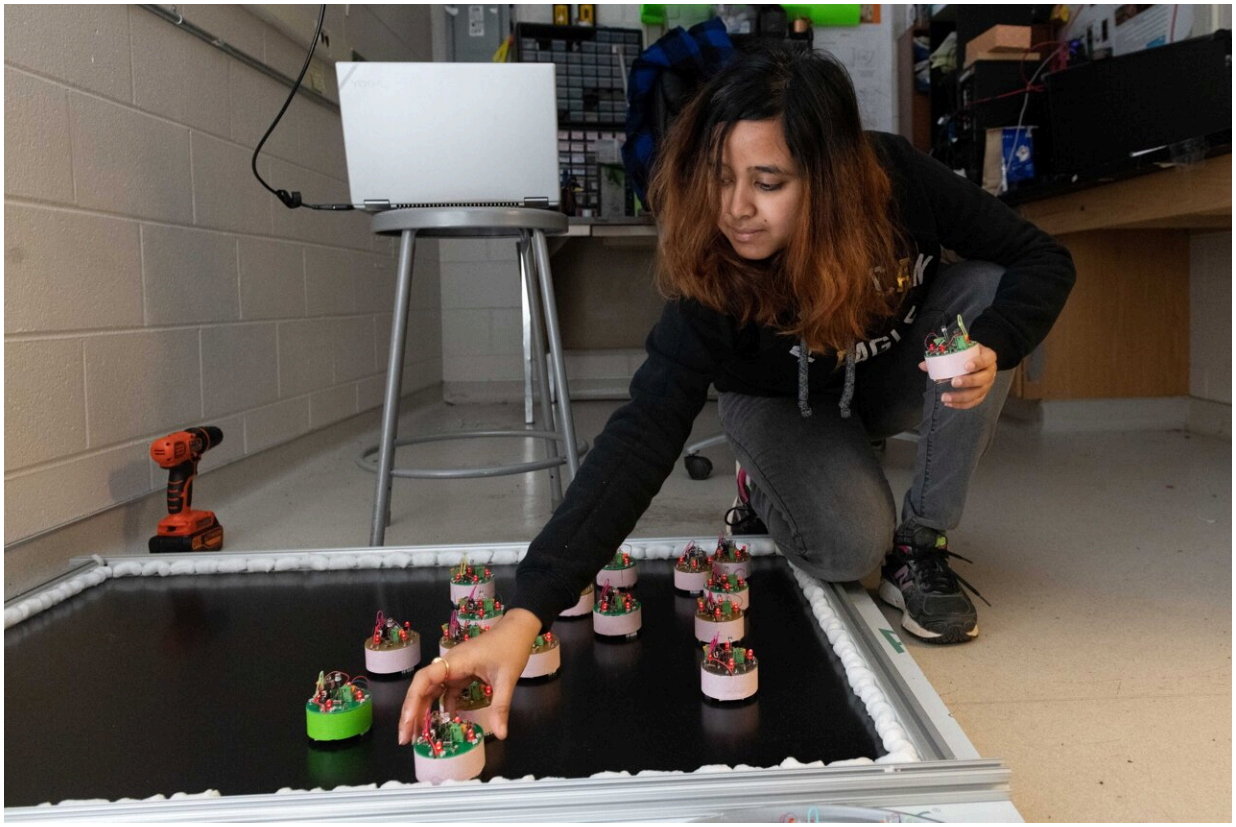
When sensors, communication, memory and computation are removed from a group of simple robots, certain sets of complex tasks can still be accomplished by leveraging the robots' physical characteristics, a trait that a team of researchers led by Georgia Tech calls "task embodiment." Credit: Shengkai Li, Georgia Tech

Anyone with children knows that while controlling one child can be hard, controlling many at once can be nearly impossible. Getting swarms of robots to work collectively can be equally challenging, unless researchers carefully choreograph their interactions—like planes in formation—using increasingly sophisticated components and algorithms. But what can be reliably accomplished when the robots on hand are simple, inconsistent, and lack sophisticated programming for coordinated behavior?

A team of researchers led by Dana Randall, ADVANCE Professor of Computing and Daniel Goldman, Dunn Family Professor of Physics, both at Georgia Institute of Technology, sought to show that even the simplest of robots can still accomplish tasks well beyond the capabilities of one, or even a few, of them. The goal of accomplishing these tasks with what the team dubbed "dumb robots" (essentially mobile granular particles) exceeded their expectations, and the researchers report being able to remove all sensors, communication, memory and computation—and instead accomplishing a set of tasks through leveraging the robots' physical characteristics, a trait that the team terms "task embodiment."

The team's BOBbots, or "behaving, organizing, buzzing bots" that were named for granular physics pioneer Bob Behringer, are "about as dumb as they get," explains Randall. "Their cylindrical chassis have vibrating brushes underneath and loose magnets on their periphery, causing them to spend more time at locations with more neighbors." The experimental platform was supplemented by precise computer simulations led by Georgia Tech physics student Shengkai Li, as a way to study aspects of the system inconvenient to study in the lab.



Bahnisikha Dutta, a graduate student at Georgia Tech, is part of an interdisciplinary research team that creates and studies magnetic robots. Credit: Allison Carter, Georgia Tech

Despite the simplicity of the BOBbots, the researchers discovered that, as the robots move and bump into each other, "compact aggregates form that are capable of collectively clearing debris that is too heavy for one alone to move," according to Goldman. "While most people build increasingly complex and expensive robots to guarantee coordination, we wanted to see what complex tasks could be accomplished with very simple robots."

Their work, as reported April 23, 2021 in the journal *Science Advances,* was inspired by a theoretical model of particles moving around on a chessboard. A theoretical abstraction known as a self-organizing particle system was developed to rigorously study a mathematical model of the BOBbots. Using ideas from probability theory, statistical physics and stochastic algorithms, the researchers were able to prove that the theoretical model undergoes a phase change as the magnetic interactions increase—abruptly changing from dispersed to aggregating in large, compact clusters, similar to phase changes we see in common everyday systems, like water and ice.

Dana Randall, Daniel Goldman, and Bahnisikha Dutta work together on creating magnetic robots. This photo was taken in 2019 at Georgia Tech as part of a previous research study. Credit: Allison Carter, Georgia Tech

"The rigorous analysis not only showed us how to build the BOBbots, but also revealed an inherent robustness of our algorithm that allowed some of the robots to be faulty or unpredictable," notes Randall, who also serves as a professor of computer science and adjunct professor of mathematics at Georgia Tech.

More information: Shengkai Li et al, Programming active cohesive granular matter with mechanically induced phase changes, *Science Advances* (2021). DOI: 10.1126/sciadv.abe8494

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