# This fungus cell only looks like the 405 freeway (w/ Video)

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No, those are not cars darting along a busy highway. The glowing specks you're seeing in the video are millions of nuclei flowing through the tube-like filaments, or hyphae, of a single fungus cell.

The video was produced as part of a study by UCLA mathematician Marcus Roper's research group that was the first to measure and explain this dynamic movement of nuclei in the cells of a fungus.

"It's complex, beautiful and so dynamic," said Roper, an assistant professor of mathematics and the lead author of two new studies that cast light on how cells ingeniously adapt to physical challenges.

The research, conducted with a group led by UC Berkeley life scientist Louise Glass, focused on the fungus Neurospora crassa. Fungus cells, unlike animal and plant cells, can contain more than one nucleus, and in N. crassa cells, multiple, genetically different nuclei coexist in the same cell space.

Having genetically different nuclei within a single cell benefits a fungus by making it more infectious, Roper said. However, this advantage only works if each part of the fungus contains a mixture of each type of genetically different nuclei.

This is where the traffic-like flow comes in. As the cell's tubular filaments containing the nuclei grow, the flow process continuously distributes the different nuclei throughout the fungus cell, keeping them well mixed for maximum advantage.

"The fungus is keeping all of its nuclei very well mixed. If the nuclei weren't all traveling along complex highways, they would separate out as the fungus grows," Roper said. "As you go deeper into the colony, the flow gets more complicated. It's like a traffic system. It starts to look like the 405 Freeway. As the nuclei move around, sometimes they find shortcuts. Sometimes there are traffic jams."

But what, precisely, conducts this nuclear traffic?

The flow, Roper and his colleagues discovered, is "propelled by pressure gradients across the colony in a complicated, mutely-directional network." By demonstrating how a variety of different pressures throughout the colony determine the speed and direction of flow, Roper illustrates how the apparently random network of tubes is actually exquisitely engineered to optimally mix the nuclei.

"To understand whether this mixing is engineered into the fungus, we need to figure out mathematically what the alternatives are," said Roper, who received an Alfred P. Sloan Foundation Research Fellowship last year.

To that end, the researchers studied the geometry of the network and then compared it to alternative, mathematically generated networks to see whether the fungus' natural network was optimal for mixing the genetically different nuclei. They found that it was.

To confirm their finding, they muted a gene in the fungus cell, changing the network. They found that in the genetically altered network, the nuclei tended to segregate out—that is, nuclei that were the same genetically tended to group together rather than mix.

"The flow helps the fungus tolerate being genetically diverse within itself," Roper said. "That is not something any other class of organism does. There are millions of species of fungi, and many of them have this internal genetic diversity. In a person, we have a word for genetic diversity: cancer. But the fungus doesn't mind; it helps the fungus."

## The benefits of being multicellular

Roper's goal is to apply mathematics to make new discoveries about how cells solve physical challenges. Those challenges—and the solutions organisms have found for them—have left deep imprints on how life has evolved.

For instance, how and why did multicellular life arise? To help answer that, Roper has been studying an organism in a family known as the choanoflagellates—the closest single-celled cousins of multicellular animals. Scientists believe that something remarkable must have happened following the divergence of choanoflagellates from the multicellular animals to create conditions favoring complex multicellular life.

Interestingly, it was recently discovered that one species of the single-celled choanoflagellates—Salpingoeca rosetta, which lives in muddy coastal areas and feeds on bacteria—can form colonies ranging from two cells to a couple dozen. The discovery surprised Roper.

"It's like watching a fish walk onto land—seeing evolution in action," he said. "If we can understand the conditions that make this transition occur, maybe we can understand why multicellularity arose among animals in the first place."

Is there any advantage to S. rosetta being mutlicellular? Roper found an answer in fluid dynamics. In research published recently in the journal

*Physical Review Letters*, he and his colleagues report that multicellular S. rosetta colonies generate collective fluid flows that improve the cells' ability to feed.

A single cell's tail, or flagellum, allows the cell to swim and helps bring toward the cell fluid containing the bacteria on which it feeds. Generally, multicellular organisms can swim faster and therefore encounter more food.

But multicellular S. rosetta colonies seem, at first glance, to be less adept at these activities, Roper said. The colonies swim more slowly and poorly than single cells. The flagella of the cells extend in various directions, like a rowboat whose passengers steer their oars in different directions. So is there any benefit at all for these colonies?

Although this "multiple oars" chaos does hinder the colony's ability to swim, Roper said, it actually helps to bring distant bacteria-containing fluid to the colony much faster than is possible with a single-celled S. rosetta.

"It is not at all obvious from the biology that there would be any benefit to being multicellular," Roper said. "But we found a benefit."

Co-authors of this research are Patrick Hickey, a postdoctoral scholar in Roper's group at UCLA; Anna Simonin of Australia's University of Western Sydney; and Abby Leeder, N. Louise Glass, Mark J. Dayel, Rachel E. Pepper and M.A.R. Koehl of UC Berkeley.

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