Can Answers to Evolution Be Found in Slime?

Steven L. Stephenson

MORE THAN MEETS THE EYE While naturalists have known of slime molds for centuries, only now are scientists really starting to understand them. More Photos »

By CARL ZIMMER
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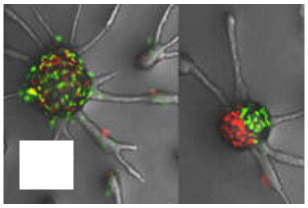
Most of the aliens that come out of Hollywood don't really look alien at all. They may have pizza-size eyes or roachlike antennae, but their oddities are draped on a familiar humanoid frame.

If you want to find life forms that truly seem otherworldly, your local forest is a much better place than your local cineplex. It is home to creatures that are immensely old, fundamentally bizarre and capable of startlingly sophisticated behavior. They are the slime molds.

Slime molds are a remarkable lineage of amoebas that live in soil. While they spend part of their life as ordinary single-celled creatures, they sometimes grow into truly alien forms. Some species gather by the thousands to form multicellular bodies that can crawl. Others develop into gigantic, pulsating networks of protoplasm.

Beauty and the Blob



Dictyostelium, Connected and Unconnected

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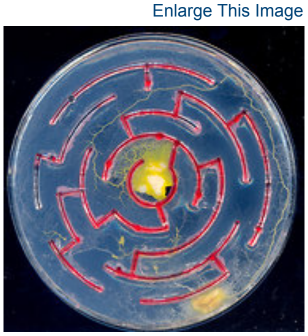

Andy Adamatzky

FINDING ITS WAY In an experiment, a slime mold in the outside chamber made it to an oat flake in the central chamber of a maze. More Photos »

While naturalists have known of slime molds for centuries, only now are scientists really starting to understand them. Lab experiments are revealing the complex choreography of signals in some species that allows 20,000 individuals to form a single sluglike body.

The pulsating networks that some slime molds form are giving other scientists clues to solving difficult mathematical problems. In 2000, Japanese researchers placed Physarum polycephalum — the name means "many-headed slime mold" — in a maze, along with two blocks of food. It extended its tendrils down the corridors of the maze, bending around curves, reaching dead ends and then backing out of them. After four hours, the slime mold was feasting on both blocks of food.

Andrew Adamatzky, a researcher at the University of West England, has been watching slime molds since 2006, finding inspirations in their growth for designing computer software. He has made electronic music using molds, and a favorite hobby is challenging them to build highway systems. In 2010 he and his colleagues placed a slime mold in the middle of a map of Spain and Portugal, with pieces of food on the largest cities. The slime mold grew a network of tentacles that was nearly identical to the actual highway system on the Iberian Peninsula.

"If some countries started to build highways from scratch, I would recommend to them to follow the slime mold routes," Dr. Adamatzky said.

Despite their name, slime molds are not related to bread mold or the black mold that grows in damp houses. They belong to a separate lineage that evolved from ordinary soil amoebas.

By analyzing the DNA of different slime mold species, researchers are reconstructing their evolutionary history, which turns out to reach back about a billion years. Since all known slime molds live on land, that suggests that they were early pioneers, arriving hundreds of millions of years before animals or plants.

"They may be as old as the terrestrial ecosystem," said Sandra Baldauf, an evolutionary biologist at Uppsala University in Sweden.

Slime molds first came to scientific fame in the mid-20th century with the work of the Princeton biologist John Tyler Bonner. Dr. Bonner learned of a North American species of slug-forming slime mold called Dictyostelium discoides and began to raise them in his lab, studying them as a simple analog of animal embryos.

Today, biologists no longer think of Dictyostelium as an embryo: It is more like a society of amoebas that come together for a common cause, for which some will sacrifice themselves.

The organisms respond to starvation by rushing together by the thousands into a single blob. The blob stretches out into a slug-shaped mass about one millimeter long (one twenty-fifth of an inch), which then crawls like a worm toward light.

Once it reaches the surface of the soil, the slug undergoes another transformation: Some of the cells turn into a stiff stalk, while the others crawl to the top and form a sticky ball of spores. They stick to the foot of an animal and travel to a hospitable place.

Inside the slug, about 1 percent of the amoebas turn into police. They crawl through the slug in search of infectious bacteria. When the amoebas find a pathogen, they devour it. These sentinels then drop away from the slug, taking the pathogen with it. They then die of the infection, while the slug remains healthy.

When the slug is ready to make a stalk, more amoebas must die so that others can live. They climb on top of one another and transform their insides into bundles of cellulose. Twenty percent of Dictyostelium cells die this way, allowing the survivors to climb up their lifeless bodies and become spores.

David Queller and Joan Strassmann, a husband-and-wife team of Dictyostelium experts at Washington University in St. Louis, have found that some strains of the slime mold are natural-born cheats. If they are mixed with other strains, they are more likely to end up as spores than as dead stalk cells. "Clearly this is not just a weird thing," Dr. Queller said. "Those mutations happen all the time."

Research by Dr. Queller and Dr. Strassmann has revealed some reasons the slime-mold world has not been overwhelmed by these cheats. For one thing, most of the amoebas that form a slug are closely related to one another.

"They're helping relatives," Dr. Strassmann said. Even if the slime molds die to form a stalk, many of their genes are passed on to the next generation through their kin.

To help relatives, Dictyostelium needs a way to recognize them. Researchers at Baylor College of Medicine in Houston recently figured out part of the way the slime molds tell kin from strangers. The amoebas make a pair of proteins on the surface of their cells, which fit snugly together — like "patches of Velcro," as one researcher, Gad Shaulsky, put it.

Dr. Shaulsky and his colleagues reported in July that if these proteins cannot link to each other, amoebas cannot fuse. "They completely ignore each other," said Adam Kuspa, another Baylor biologist.

Dictyostelium belongs to one of the two great branches of slime molds. Its branch is known as the cellular slime molds, because its spore and stalk are made out of many cells.

By contrast, the so-called acellular slime molds do not form slugs. Instead, two cells merge, combining their DNA into a new single-celled organism that just keeps growing — extending tentacles that can extend as far as several yards. It pulsates to pump food from its extremities to its core, and it can even crawl to search for food.

"You see one on a log, and then you come back a few hours later and it's gone," said Steven L. Stephenson, a slime mold expert at the University of Arkansas.

Eventually, acellular slime molds also make spores. They produce tens of thousands of stalks, and the spores that cap them blow away in the wind.

Dr. Adamatzky, the researcher who watched acellular molds form highwaylike patterns, has also used them to simulate a nuclear disaster. He and his colleagues grew a slime mold network of highways for Canada, then placed a crystal of sea salt — which repels slime molds — on the map where the Bruce nuclear power plant is located, on Lake

Huron in Ontario.

The slime mold abandoned its tendrils near the salt and then grew a new highway pattern that efficiently rerouted food across Canada. “Reactions to spreading contamination may shed some light what would happen if real disasters occur,” Dr. Adamatzky said.

Building networks sometimes requires tough decisions from slime molds. At the University of New South Wales in Australia, Madeleine Beekman and her colleagues recently documented the decision-making of slime molds by presenting Physarum with two different kinds of food: either rich in protein, or rich in carbohydrates. The slime molds grew tendrils to both foods, but adjusted their sizes to get the best balance of protein and carbohydrates that allowed them to grow fastest.

In another experiment, Dr. Beekman and her colleagues made the choice harder by putting food under bright lights, which Physarum tries to avoid. In the first trial, the scientists offered the slime mold food chunks that contained 3 percent oat flakes in the dark, and 5 percent oat flakes in bright light.

The mold was just as likely to ooze toward either kind of food. But when the scientists added a 1 percent chunk to the dark area, that was enough to tip the balance: Even though there was still not as much oat in the dark, 80 percent of the mold now oozed in that direction.

This might seem an irrational switch, but it is one that humans make as well. Psychologists have found that the value we put on things depends greatly on the other things we can choose from. Humans and slime molds alike choose according to relative values, rather than trying to calculate absolute ones.

Scientists know a lot about the two lab-friendly species Physarum and Dictyostelium, but they still know very little about the many other slime molds on earth. In 2003, Dr. Stephenson and other slime mold experts embarked on a worldwide expedition to get a better understanding of the global diversity of these creatures.

The Global Eumycetozoan Project, based at the University of Arkansas, has doubled the known species of slime molds. Biologists have found slime molds in Antarctica, in barren deserts, high in the canopies of jungles and even on the leaves of household plants.

“Every place people have looked for them, they’re there,” Dr. Stephenson said.

Slime molds are also present in huge numbers: There may be thousands of individual slime molds in a pinch of soil. Their collective hunger makes them a powerful ecological player. When plants and animals die, microbes break them down; slime molds then devour many of the bacteria, releasing their nutrients for other organisms to grow on.

“If you removed those slime molds, the whole earth’s ecosystems would be very different,” Dr. Stephenson said.

As scientists sequence the DNA of new species, they can finally start to figure out how slime molds evolved; genetic studies have confirmed, for example, that the two main groups of slime molds are each other’s closest relatives.

Other studies have shown that the slime mold lineage is immensely old. In a paper to be published in the journal Genome Research, British and German scientists estimate that the cellular slime molds evolved 600 million years ago. Preliminary studies suggest that the common ancestor of all living slime molds is much older than that.

If slime molds arrived on land close to a billion years ago, they may well have colonized continents that were home only to films of bacteria. "They might be tightly linked to the development of soil on land," said Dr. Baldauf, the Swedish biologist, who is analyzing the DNA of species discovered in the Eumycetozoan Project.

The traits that slime molds share in common, like making spores, may have first evolved as they came ashore. The ancestors of Dictyostelium may have evolved the ability to form slugs and stalks to get those spores out of the ground, so that they'd have a better chance to spread. The giant acellular slime molds chose a different strategy, spreading their bodies across huge areas, and making spores across their entire surface.

Finding new species of slime molds will let scientists test these possibilities, Dr. Baldauf said. While she is impressed with all the species Dr. Stephenson and his colleagues have found, she is sure there are many more waiting to be discovered.

"I think it's the tip of the iceberg," she said. "They go to some incredible place like a mountain in Patagonia, and they take a tiny soil sample and bring it back. But who knows what's a foot away?"

This article has been revised to reflect the following correction:

Correction: October 4, 2011

An earlier version of this article misstated the proportion of Dictyostelium cells that die to allow the other amoebas they have congregated with to form spores. It is 20 percent, not 80 percent.

A version of this article appeared in print on October 4, 2011, on page D1 of the New York edition with the headline: Can Answers to Evolution Be Found in Slime?.

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