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Our Silent Partners

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Merlin Sheldrake explores how fungi challenge our understanding of nonhuman intelligence and complicate the boundaries between one organism and another.

Reviewed:

Entangled Life: How Fungi Make Our Worlds, Change Our Minds and Shape Our Futures
by Merlin Sheldrake.
Random House, 352 pp., $28.00; $18.00 (paper)

Imagine that you are afloat on your back in the sea. You have some sense of its vast, unknowable depths—worlds of life are mostly darting about beneath you. Now imagine lying in a field, or on the forest floor. The same applies, though we rarely think of it: the dirt beneath you, whether a mile or a foot deep, is teeming with more organisms than researchers can quantify. Their best guess is that there are as many as one billion microbes in a single teaspoon of soil. Plant roots plunge and swerve like superhighways with an infinite number of on-ramps. And everywhere there are probing fungi.

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Fungi are classified as their own kingdom, separate from plants and animals. They are often microscopic and reside mostly out of sight—mainly underground—but as Merlin Sheldrake writes in *Entangled Life: How Fungi Make Our Worlds, Change Our Minds and Shape Our Futures*, they support and sustain nearly all living systems. Fungi are nature's premier destroyers and creators, digesting the world's dead and leaving behind new soil. When millions of hair-like fungal threads—called hyphae—coalesce, felting themselves into complex shapes, they emerge from the ground as mushrooms. A mushroom is to a fungus as a pear is to a pear tree: the organism's fruiting body, with spores instead of seeds. Mushrooms disperse spores by elaborate means: some species generate puffs of air to send them aloft, while others eject them by means of tiny, specialized catapults so they accelerate ten thousand times faster than a space shuttle during launch.[1]

But Sheldrake is most interested in fungi's other wonders—specifically, how they challenge our understanding of nonhuman intelligence and stretch the notion of biological individuality. Fungi infiltrate the roots of almost every plant, determining so much about its life that researchers are now asking whether plants can be considered plants without them. They are similarly intertwined throughout the human body, busily performing functions necessary to our health and well-being, or, depending on the fungi's species and lifestyle, wreaking havoc. All of this prompts doubts about what we thought we knew to be the boundaries between one organism and another.

Sheldrake is a biologist with a specialty in tropical ecology, and *Entangled Life* combines scientific research with his experiences in the field. He received his Ph.D. from Cambridge, researching the tropical rainforests of Panama, where a ghostly white flowering plant of the genus *Voyria* survives not by photosynthesis but through a relationship to a tropical fungus that feeds it minerals through its roots. He also moves easily into the realm of philosophy, particularly to make sense of discoveries that push the limits of current scientific understanding. (His father is Rupert Sheldrake, a Cambridge biochemist turned parapsychologist famous for his inquiries into the paranormal and for his work on panpsychism, the school of thought that views all matter as experiencing consciousness.) Where others see a wall separating science from speculation, Sheldrake sees food for fungal thought—more opportunity to, like fungal networks, "stitch organisms into relation."

He careens around the research, pausing here and there for personal discursions and anarcho-scientific antics. He describes eating a spoonful of spore "caviar" to remind himself that fungi, so often reduced in research papers to computer models and theoretical hypotheses, are still earthy things: "One can't eat a machine or a concept," he writes. He takes LSD—a molecule originally synthesized from a fungus—to better understand mushroom motivations, and he informs readers that the illustrations for the book were drawn with ink from the shaggy ink cap mushroom, a specimen capable of erupting through asphalt and lifting heavy paving stones overnight. In another chapter Sheldrake describes a plan to inoculate a copy of *Entangled Life* with oyster mushroom spores, then cook and eat the fungi that have eaten his book. You can see him actually do it on YouTube—thus, he points out, eating his words.

Fungi themselves form large networks of hyphae strands in order to feed. These strands, when massed together, are called mycelium. The total length of mycelium threaded through the globe's uppermost four inches of soil is believed to be enough to span half the width of our galaxy. Mycelium is constantly moving, probing its surroundings in every direction and coordinating its movements over long distances. When food is found—a nice chunk of rotting wood, for example—disparate parts of the mycelium redirect to coalesce around it, excrete enzymes that digest it externally, and then absorb it. As Sheldrake puts it, "The difference between animals and fungi is simple: Animals put food in their bodies, whereas fungi put their bodies in the food."

Fungi are literally woven into the roots and bodies of nearly every plant grown in natural conditions. "A plant's fungal partners," Sheldrake writes, "can have a noticeable impact on its growth." In one striking example, he describes an experiment in which strawberries grown with different fungal partners changed their sweetness and shape. Bumblebees seemed able to discern the difference and were more attracted to the flowers of strawberry plants grown with certain fungal species. Elsewhere he discusses an experiment in which researchers took fungi that inhabited the roots of a species of coastal grass that grew readily in saltwater and added it to a dry-land grass that could not tolerate the sea. Suddenly the dry-land grass did just fine in brine.

Much has been written lately about trees communicating and sharing resources among themselves; healthy trees have been documented moving resources toward trees that have fallen ill.[2] This is often characterized as friendship or altruism between trees, but it is not at all clear whether trees pass information or nutrients intentionally. What is clear, though, is that the fungal networks entwined in every tree root make this communication possible. "Why might it benefit a fungus to pass a warning between the multiple plants that it lives with?" Sheldrake asks. The answer is survival: "If a fungus is connected to several plants and one is attacked by aphids, the fungus will suffer as well as the plant," he writes. "It is the fungus that stands to benefit from keeping the healthy plant alive."

At first glance, hyphae, which are hollow, might seem like simple plumbing systems for plants to exchange signals and nutrients. But fungi are pursuing their own interests as well—running nutrient economies, controlling the flow of supply and demand. As far as scientists can tell, it works something like this: because fungi, being underground, can't photosynthesize, they must get their supply of life-sustaining carbon from plants, who spend all day making carbon out of sunlight and air. In exchange for carbon, fungal hyphae supply plants with the soil minerals they sequester from below, which plants need but can't get on their own. As Sheldrake explains it, fungi "stitch the atmosphere into relation with the ground."

The entanglement is symbiotic, but that doesn't mean everyone involved benefits equally. Fungi in some cases have been found to "charge" a plant more carbon in exchange for the transfer of a smaller amount of phosphorous when the mineral is scarce, and to do the opposite when phosphorous is abundant. Scientists still don't know how fungi manage these interactions, much less how they coordinate their dealings across vast mycelium mats.

Some evidence suggests that plants—which initially came onto the evolutionary scene as greenish blobs of algae—developed their first leggy forms precisely to house beneficial fungi. "What we call 'plants' are in fact fungi that have evolved to farm algae, and algae that have evolved to farm fungi," Sheldrake argues. So what is a plant, really, without its fungal collaborators? Perhaps not a plant at all.

Yet despite fungi's pervasive presence in the natural world, scientists estimate that only 6 percent of fungal species have been described. (There are believed to be between 2.2 and 3.8 million of them in existence—six times the number of plant species.) This is partly because scientists are still learning where to look: since mycelium is belowground, very little of its interactions can be seen without a microscope, and the ubiquity of hyphae inside other organisms—like the roots of plants—is a relatively recent discovery.

This is perhaps the most important point of Sheldrake's book: a reminder to be humble in the face of the limits of what science knows or can know. We simply don't know all they can do, or even what they are. In looking at the limits of our current understanding, Sheldrake argues, we also begin to recognize limits in our knowledge about ourselves.

Fungi are genetically closer to animals than to plants, and similar enough to humans at the molecular level that we benefit from many of their biochemical innovations. In fact, many of our pharmaceuticals are borrowed innovations from fungi. Penicillin, discovered in 1928 by the Scottish researcher Alexander Fleming, is a compound produced by fungus for protection against bacterial infection. The anti-cancer drug Taxol was originally isolated from the fungi that live inside yew trees. More than half of all enzymes used in industry are generated by fungi, Sheldrake notes, and 15 percent of all vaccines are produced using yeast. We are, as he puts it, "borrowing a fungal solution and rehousing it within our own bodies."

In Louie Schwartzberg's 2019 documentary *Fantastic Fungi*—which includes mesmerizing time-lapses of mushrooms growing and animations of mycelium spreading through soil—the prominent mycologist Paul Stamets describes treating his mother's stage-four breast cancer with mushroom supplements, and using fungi that attack insects to replace pesticides. The film also looks at mycoremediation—a small but growing environmental practice that uses fungi to eliminate toxic substances from soils—and presents fungi as crucial to the survival of the ailing planet.

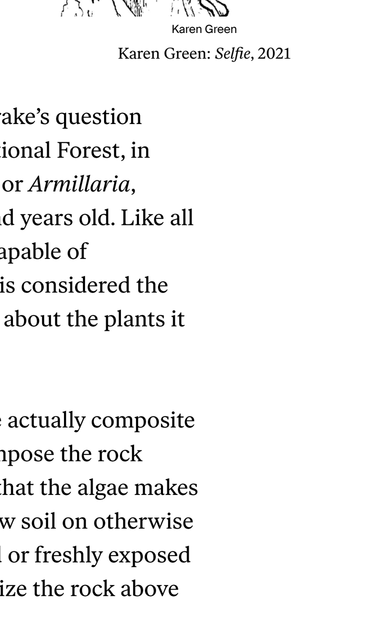
Fungi can clean up our messes. In *Entangled Life*, Sheldrake mentions an organization called CoRenewal that is researching whether local "petrophilic" fungus strains in the Ecuadorian Amazon can be used to help break down poisonous byproducts of crude oil left behind by Chevron's operations there. Some fungi species are able to harness radioactivity as a source of energy, similar to how plants use sunlight to grow; a nuclear reactor at Chernobyl is home to a large population of these radiotrophic fungi. After Hiroshima was decimated by an atomic bomb, Sheldrake writes, "it is reported that the first living thing to emerge from the devastation was a matsutake mushroom."[3]

Even while we benefit from fungi, we are also interfering with them. Antifungal sprays create superbugs out of destructive fungi that build up resistance to them, in much the same way that antibiotics create strains of resistant bacteria. Sheldrake also points out that humans are causing the spread of *Batrachochytrium dendrobatidis*, a fungus that infects amphibians with the most deadly disease ever recorded in any species. People carry it from region to region through global shipping; in the five decades since it emerged, it has already driven ninety species to extinction and is threatening to wipe out many more.

Perhaps the most popular mystery of fungi is how they manage to alter our consciousness. While books like Michael Pollan's 2018 best seller *How to Change Your Mind* explore the human response to psychedelics,[4] Sheldrake, ever interested in what he calls the "fungal point of view," asks what's in it for the mushrooms. No one yet knows why psychedelic mushrooms synthesize psilocybin, the compound responsible for our altered states. Yet some two hundred species of mushrooms found all over the world do it.

Scientists have proposed several theories about fungal motivations, one of which is inspired by *Ophiocordyceps unilateralis*, a fungus whose spores infiltrate the bodies of ants and quickly commandeer their nervous systems. Once inoculated with cordyceps, the ants abandon their usual routines and march straight up trees, where they perform a "death grip," biting down hard on the underside of a leaf to anchor themselves. Mycelium sprouts from the ants' feet and "stitches them to the plant's surface," Sheldrake writes. Then, a cordyceps mushroom erupts out of each ant's head, killing the ant. The mushroom disgorges its spores, which rain down on the ants scurrying beneath and infect them, spreading the cycle of zombification and reproducing the cordyceps. For part of its life cycle, then, the cordyceps could be said to wear an ant's body, using it to act through.

Channeling the work of the psychedelic plant-theorist Terrence McKenna, a family friend of Sheldrake's,[5] the author asks, "Do psilocybin fungi 'wear our minds,'" as *Ophiocordyceps* wears ant bodies? After all, human behavior notably changes during and after consuming magic mushrooms—many report mystical experiences that impart a sense of awe and interconnection, a new understanding about the nature of reality, and a lessening of a clearly defined sense of self. Thousands of years of psilocybin mushroom use have left distinct traces in diverse human cultures, from chants to religious beliefs and devotional art.



Karen Green: *Selfie*, 2021

The gene cluster responsible for psilocybin seems to have evolved separately in fungi several times, and to have jumped, via gene transfer, between species. According to Sheldrake, that alone suggests it must have provided "a significant advantage to any fungi who expressed it." But what's useful to fungi in the behavior of humans and other animals while under the influence of psilocybin? In McKenna's view, fungi borrow the human body in an attempt, perhaps—as Sheldrake puts it—to "deflect our destructive habits as a species," influencing a symbiotic partnership with possibilities "richer and even more baroque" than could be achieved by either humans or fungi alone.

This explanation is speculative and may well engender skepticism, but Sheldrake's question raises others about fungi and the notion of the individual. In the Malheur National Forest, in eastern Oregon's Blue Mountains, a single mycelial network of honey fungus, or *Armillaria*, stretches for over three square miles underground and is at least two thousand years old. Like all mycelial networks, it is made up of an interconnected mat of fine filaments, capable of transferring messages and coordinating movements across its entire mass. It is considered the world's largest organism. But is it a single organism or is it a collective? What about the plants it is intertwined with?

Sheldrake also discusses lichens. Though often thought of as a plant, they are actually composite organisms of algae living among filaments of fungi. The fungi is able to decompose the rock beneath them, extracting minerals the algae needs, and in return gets sugars that the algae makes through photosynthesis. This interspecies collaboration is the basis for all new soil on otherwise inhospitable surfaces; the first gram of soil on a newly formed volcanic island or freshly exposed glacial rock was made when algae and fungi joined forces to tentatively colonize the rock above the waterline for the first time, and together slowly weathered it.

Since the 1860s, when the Swiss botanist Simon Schwendener first proposed the radical idea that lichens were composed of more than a single organism, it was assumed that they were a binary: a marriage of one alga and one fungus. The presence of anything else—like more than one species of fungi or a few bacteria—was considered merely contamination. Sheldrake writes that several years ago, when the lichenologist Tony Spribille was challenged by a friend to grind up a lichen and try to sequence the DNA of every participant organism, Spribille expected the result textbooks told him to expect: two partners, a fungus and an alga. However, other organisms showed up far too often to be happenstance. Eventually, he realized that contamination was the rule in these symbiotic relationships, not the exception, and thus inherent to lichen's essential identity and function. "There was no such thing as lichens without 'contamination,'" he tells Sheldrake, and no two composites were the same. Spribille published his findings in 2016, shaking up the field of lichenology.

Sheldrake and Spribille are both proponents of using queer theory to find new ways of understanding fungi where science has yet to draw a map.[6] "The human binary view has made it difficult to ask questions that aren't binary," Spribille says. "Our strictures about sexuality make it difficult to ask questions about sexuality, and so on.... And this makes it extremely difficult to ask questions about complex symbioses like lichens." As I read *Entangled Life*, I found myself thinking that perhaps this has held us back from seeing what is abundantly evident: that queerness, in its embrace of infinite variation and fluctuating identities, has always been natural.

"We are all lichens," the biologist Scott Gilbert and his colleagues wrote in a 2012 paper published in the *Quarterly Review of Biology*. Titled "A Symbiotic View of Life: We Have Never Been Individuals," the paper argues that human bodies cannot be thought of as individual organisms. Rather, we are dynamic colonies housing a shifting community of trillions of bacteria and fungi that perform many vital functions and determine our health (including a "microbial cloud" that overflows our body, hovering, at all times, in the air around us). From this point of view, "I" has always truly been "we." While much research and discussion has been devoted to the bacterial constituents of our microbiomes in recent years, fungi play just as vital a part in governing our internal ecosystems, particularly our digestive and immune systems. Despite this, fewer than one percent of all scientific papers published on the microbiome concerns its fungal constituents.

For all its engagement with philosophy and queer theory, Sheldrake's book isn't terribly political. At one point he blithely mentions that the US Defense Department was funding research into the potential of growing soldier barracks from mycelium. What, one wonders, are the implications of conscripting fungi to support military aims? But Sheldrake's primary focus is not on how fungi might be used—it is on discovering what they actually are, which, even by the end of *Entangled Life*, remains unresolved.

We know that fungi maintain "countless channels of chemical communication with other organisms," and that they are constantly processing diverse information about their environment. Some can recognize color, thanks to receptors sensitive to blue and red light, though it is not entirely clear what they do with that information. Some even have opsins, light-detecting proteins also found within the rods and cones of the animal eye. One fungus, *Phycomyces blakesleeanus*, has a sensitivity to light similar to that of a human eye and can "detect light at levels as low as that provided by a single star" to help it decide where to grow. It is also able to sense the presence of nearby objects and will bend away from them before ever making contact. Still other fungi recognize texture; according to Sheldrake, the bean rust fungus has been demonstrated to detect grooves in artificial surfaces "three times shallower than the gap between the laser tracks on a CD."

Can fungi, then, be said to have a mind of their own? That is, as Sheldrake puts it, a "question of taste"—there is no settled scientific definition for "intelligence," not even for animals. The Latin root of the word means "to choose between," an action fungi clearly do all the time. But the application of this kind of term to fungi is loaded with something more mystical than that simple definition and demands a willingness to rattle our sense of where we ourselves fall in the imagined hierarchy of life. If fungi can be said to think, it is a form of cognition so utterly different that we strain to see it.

Despite the radical otherness of fungi, scientists have suggested that there are similarities between our nervous systems and the way mycelial networks might process information. Any mycelial network could have "between hundreds and billions of hyphal tips, all integrating and processing information on a massively parallel basis," Sheldrake writes. How they coordinate information from one end of a mycelial mat to another remains a mystery, but a leading possibility is electricity. Stefan Olsson, a mycologist formerly at Lund University in Sweden, inserted miniature electrodes into the hyphae of a honey fungus (the same species as the giant fungus in Oregon) and detected pulses of electricity called "action potentials," which fired at about four impulses per second—a rate "very close to that of animals' sensory neurons"—and traveled across the hyphae quickly. To determine if the mycelium was using these electrical pulses to communicate throughout the organism, he offered it blocks of wood, its favorite food. When hyphae approached the wood, the firing rate of the impulse doubled, and it went back down to normal when the wood was removed.

"Olsson's findings suggested that mycelium might form fantastically complex networks of electrically excitable cells," Sheldrake writes. "Brains, too, are fantastically complex networks of electrically excitable cells." Olsson himself demurs; the word *brain* is too associated with the animal organ, he says, and clearly there is not one of those to be found in a fungus. But Sheldrake presses on: "If fungi did use waves of electrical activity to transmit signals around a network, wouldn't we think of mycelium as at least a brain-*like* phenomenon?"

After all, philosophers of mind like Daniel Dennett argue that drawing any neat line between nonhumans and humans with "real minds" is an "archaic myth." Our brains evolved from nonmental material. "Brains are just one such network," Sheldrake writes, "one way of processing information." We still don't know how the excitement of brain cells gives rise to experience. Can we really dismiss the possibility of cognition in an organism that clearly adapts, learns, and makes decisions simply based on the lack of a brain structure analogous to ours?

Perhaps there is intelligent life all around us, and our view is too human-centric to notice. Are fungi intelligent? Sheldrake reserves judgment, deferring instead to scientific mystery: "A sophisticated understanding of mycelium is yet to emerge." Still, after spending long enough in the atmosphere of Sheldrake's sporulating mind, I began to adopt the fungal perspective. I can't help now but see something like a mind wherever there might be fungal threads—which is to say everywhere, a mesh-like entangled whole, all over the earth. ■

Zoë Schlanger

Zoë Schlanger received a National Association of Science Writers award and was a finalist for the Livingston Award for her reporting on climate change and environmental health. She is writing a book about plant intelligence, *The Light Eaters*. (October 2021)

1. One of these, *Pilobolus crystallinus* (also known as the Hat Thrower), is described by Aliya Whiteley in *The Secret Life of Fungi: Discoveries from a Hidden World* (Pegasus, 2021). ↩
2. See, for example, Suzanne Simard, *Finding the Mother Tree: Discovering the Wisdom of the Forest* (Knopf, 2021). ↩
3. For more on the prized (and expensive) matsutake, which is also known to flourish in areas that have previously been decimated by logging, see Anna Lowenhaupt Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins* (Princeton University Press, 2015). Tsing, an anthropologist, did something unusual for the genre of ethnography: by framing the unique environmental demands of the matsutake—or as one might say, their desires—as the forces that shape the human world of pickers, middlemen, luxury market prices, and an entire culture of nostalgia and longing that springs up around it, her book attributed agency to the mushrooms and disabused readers of the illusion of a rigid distinction between the human and mushroom worlds. ↩
4. See also Mike Jay's review in these pages of Carl Hart's *Drug Use for Grown-Ups* (Penguin, 2021) and Michael Pollan's *This Is Your Mind on Plants* (Penguin, 2021), September 23, 2021. ↩
5. A succinct review of McKenna's views on fungi can be found in Lawrence Millman, *Fungipedia: A Brief Compendium of Mushroom Lore* (Princeton University Press, 2019). ↩
6. Among the articles Sheldrake cites is David Griffiths, "Queer Theory for Lichens," *UnderCurrents*, Vol. 19 (2015). ↩