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COOPERATION, NOT COMPETITION, MAY DRIVE EVOLUTIONARY DIVERSITY ON EARTH

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LIFE ACCORDING TO GAIA

In the beginning there were bacteria, simple one-celled creatures that formed from the young earth's gas and mineral seas. These primitive organisms quickly began devouring the chemical Garden of Eden that surrounded them. They were fruitful and multiplied, expanding throughout the oceans and onto the rocky shores. When the garden began to grow sparse, the bacteria adapted, mutating into altered versions of themselves. These creatures thrived as well.

And then something remarkable happened. Bacteria began to merge with one another in cooperative unions. What one bacterium could not do by itself, it achieved with the aid of another. They divided up the labors of life, each partner specializing in different tasks. Over time, the bacteria that had entered into mutual alliances, or symbiotic partnerships, lost their ability to survive on their own. Eventually, these cohabiting bacteria evolved into a dramatically new type of two-part being—the eukaryote, an advanced cell that carries within itself a powerhouse of an organ called a nucleus, a specialized vessel for genes. The emergence of eukaryotes was a leap in evolutionary complexity far greater than any that has occurred since. All the plants and animals we know today, everything from the daffodil to the dolphin, developed from these early symbiotic unions.

Once life on Earth was omnipresent its power over the environment escalated. Living things consumed huge amounts of some atmospheric gases and exhaled massive amounts of others. Their presence in the oceans altered the water's acid and base content. In short, living things were no longer passive passengers that merely adapted to physical events like volcanic eruptions and asteroid impacts. They were energetic participants in the regulation of their world. Organisms that kept the environment hospitable for their progeny survived; those that didn't became extinct. Living things and the planet Earth were constantly interacting and the world had forever changed.

If this scenario sounds unfamiliar, it shouldn't be surprising. It is part of a daring theory of nature known as the Gaia hypothesis. Proposed by British scientist James Lovelock some 20 years ago, the Gaia hypothesis proposes that all living things and the chemical and physical environment in which they live work together like the parts of one vast organism. Ultimately, Lovelock says, this "composite organism" manipulates the air, the land, and the sea to generate the conditions most suited to supporting life.

"Life and its environment," Lovelock explains, "constitute a single entity, which regulates physical conditions in order to keep the environment at a comfortable state for the organisms themselves."

In other words, teamwork between the physical world and the life it bears is responsible for the richly diverse living earth. It is Gaia that has kept global temperatures from rising high enough or dropping low enough to destroy all life. It is Gaia itself that has sustained the atmosphere and the oceans so that they are suitable for living organisms.

JAMES LOVELOCK'S LAB IS SET IN THE THOMAS HARDY COUNTRYSIDE OF SOUTHWESTERN ENGLAND. BUT IN A LARGER SENSE, HIS WORK STRETCHES BEYOND TO SPAN THE LIVING EARTH.

Lovelock's vision of a cooperative world is bolstered by the work of American microbiologist Lynn Margulis, a professor at the University of Massachusetts. For Margulis, cooperation among organisms, especially in the form of symbiotic unions, is the driving force behind evolution. The bonding of simple bacteria into a symbiotic union, she argues, was essential to the evolution of more sophisticated organisms. And, according to Margulis, Gaia is the largest manifestation of the symbiotic process. Like Lovelock, she believes that the earth's organisms have joined with physical processes to form one massive self-regulating organism, Gaia itself.

To say the Gaia hypothesis is controversial is putting it mildly. When Lovelock first proposed Gaia (named after the Greek goddess of the earth), the most positive response came from New Age types and "ecofreaks" who grabbed on to the idea with religious fervor. Here at last, some thought, was a scientific theory that implied a purposeful order, even consciousness, in nature. Some scientists who study the earth's physical and chemical cycles—they're called Earth systems scientists—were also intrigued by Gaia, primarily because of its focus on global feedback loops, the intricate cycles that keep oxygen levels, say, or global temperatures from fluctuating wildly.

But most of the scientific community dismissed the idea as being, at best, untestable and, at worst, poetic nonsense. Gaia's most outspoken critics were and continue to be Neo-Darwinists, evolutionary biologists who have blended Darwin's theory with studies of modern genetics. Neo-Darwinists see the world not as a sphere of cooperation, but rather as a jungle of organisms battling against one another in a fight for survival. Organisms evolve, say Neo-Darwinists, when a genetic mutation makes the organism a better competitor and thus better at passing along its genes to the next generation.

What led Lovelock and Margulis to part company with such established scientific thought? For Lovelock, it all began with Mars. In the early Sixties NASA asked Lovelock to participate in the search for life on the red planet. Lovelock viewed the space agency's approach—literally searching the planetary surface for critters—as arbitrary, something akin to looking for a needle in a haystack. "I was sure there was a better way," Lovelock recalls, and, working with NASA philosopher Dian Hitchcock, he came up with an idea. Instead of searching the surface of Mars, he suggested, why not analyze its atmosphere for the metabolic products of life? If life existed, the gases produced by photosynthesis and other biological processes would be everywhere.

Though NASA did not do it his way (later research would show the agency should have), the idea set Lovelock to thinking about the difference between dead planets like Mars and living ones like the earth.

Back home in England, he began searching scientific literature for a "comprehensive definition of life as a physical process" and was shocked at how little had been written about it. He formulated his own theory, Gaia, which he presented at a scientific conference on the origins of life in 1969. Perhaps, Lovelock muses, his paper on Gaia had been poorly presented, because virtually no one was interested, no one, that is, but Lynn Margulis. Her own work on symbiosis had rocked some biological hard hats a few years earlier, and she found Lovelock's hypothesis a promising model with which to understand nature and evolution.

Since their first meeting in the late Sixties, Lovelock and Margulis have willingly suffered the slings and arrows of outraged colleagues for the sake of Gaia. They are rebels with a cause who refuse to give in to accepted theory, believing that as scientists begin examining nature more carefully, the Gaian worldview will prevail.

Indeed, a spate of current studies have reinforced their position. Most of the studies have come from Earth systems scientists, who are discovering strong links between the activity of living things and the physical environment. One body of research, for example, indicates that without life, global temperatures would be as much as 45°C (80°F) higher than they are today. New York University researcher Tyler Volk and his colleague David Schwartzman, who spearheaded the research, examined single-celled ocean organisms that make calcium carbonate shells and deposit them at the bottom of the sea. The shells absorb carbon, effectively removing it from the atmosphere and burying it in the ocean. Removing carbon from the atmosphere cools the earth, creating conditions favorable to life.

Other research by Volk examines microorganisms that create soil by eating away at rock; without all the soil to absorb carbon from the atmosphere, the earth might conceivably be 80°F warmer than it is today. "Under those circumstances," says Volk, the planet might be "uninhabitable for all but the most primitive microbes."

Similarly, new research has shown in more detail than ever how symbiotic unions can create new organisms. The most startling study really began by accident. While conducting a series of experiments on amoebas, single-celled microorganisms, University of Tennessee scientist Kwang Jeon noticed that one batch of the creatures were sick. He studied the ill amoebas under a microscope and found that each one was infected with bacteria. Jeon nursed a number of the sick organisms back to health and found that the recovering amoebas began to reproduce even though they were still infected with bacteria. A new symbiotic organism had evolved—bacterized amoebas.

Jeon took his study one step further and exchanged nuclei, the cell organs that contain the genes, between amoebas that harbored bacteria and those that did not. Curiously, the nuclei of noninfected amoebas survived the switch, but the nuclei from amoebas that had adapted to their bacterial companions began to die. When Jeon injected the ailing amoebas with bacteria, they recovered. The symbiosis was complete: The amoebas that had once been infected with bacteria were now unable to survive without them. Jeon's discovery of evolution in progress occurred over a mere 18 months, and it was the result of a symbiotic union.

Such studies challenge the Neo-Darwinian view that evolution occurs primarily when individual organisms mutate and then pass on those mutations to offspring when and only when they confer a *competitive* advantage. Instead, in the symbiotic world the only individuals are primitive bacteria; all other forms of life, even the most complex creatures, are communities of bacteria. "Living systems become embedded in living systems," explains Gail Fleischaker, a Mellon fellow at MIT and a former philosopher of science at Boston University, "and what survives as a symbiotic relationship is of necessity a cooperation rather than a competition."

Lovelock and Margulis are convinced that as studies supporting Gaia grow in number, the competitive Neo-Darwinian paradigm will begin to crumble. In its place will be a more holistic view of nature in which competition is supplanted by cooperation. The living earth will be seen as an integrated system in which organisms and the environment coevolve.

How do Neo-Darwinists and other scientists respond to Gaia and the cooperative paradigm? Ford Doolittle, a molecular biologist at Dalhousie University in Nova Scotia, may sum up the majority opinion when he says, "It pisses me off. I get irritated at what I think is fuzzy thinking." There's certainly no malice in Doolittle's judgment. He considers Margulis a good friend and a first-rate biologist. But he disagrees with her assertions about Gaia and symbiosis.

Like most biologists, Doolittle questions the role of cooperation in evolution. The evolutionary process, he says, could not accommodate the kind of global cooperation necessary in Gaia. "Natural selection," he says, "only favors an organism that has a mutation that allows it to make more of itself. It does not favor organisms that behave themselves in a global sense." Moreover, Doolittle argues, organisms that unite in a symbiotic union do so because they gain some advantage from it. "It is really just selfishness," he says. "Cooperative efforts can evolve out of symbiosis, but the driving force is not cooperation."

Other scientists question what they see as Gaia's basic premise—that life manipulates the oceans and atmosphere to benefit itself. "Any change in the atmosphere and the oceans might be positive for some species and negative for others," says Harvard geochemist Heinrich Holland. "Who is Gaia optimizing the planet for? The theory sounds something like a post-Christian view of reality, in which the hand of God, renamed Gaia, controls the fate of the earth."

If mainstream scientific opinion is ever to embrace Gaia, Lovelock and Margulis will have to produce more rigorous evidence of its existence. In the meantime, they will continue to struggle in the competitive world of science. It is doubtful they will give in. Margulis is accustomed to fighting for what she believes, and she has successfully changed scientific thinking in the past. And Lovelock is quite at ease with his role as "freelance scientist." With no position in academe, he says, he has the freedom to think and do science in his own way. His laboratory, for instance, is in his home, Coombe Mill, a small mud-and-straw cottage set in the Thomas Hardy countryside of southwestern England. But in a larger sense his lab is not contained within the walls of his small house or even in his 30 acres of meadowland and woods, which he helped to plant. It stretches beyond the moors, the mysterious circle of Stonehenge, and the stony coasts of Cornwall. It spans the Atlantic Ocean, the deserts of Africa, the towering Andes, the Great Barrier Reef. Lovelock's laboratory is the living earth in all its multifarious incarnations. It is Gaia and he will not allow her to be dismissed without a fight. ∞

"Ethics won't allow us to pull the plug until he runs out of money."