What Is Life?

The answer depends on whom you ask. Ask an astrophysicist, and you'll hear about complex molecules, evolved from simpler molecules, with a boost from meteors falling onto the primordial Earth. Ask a neuropsychologist, and you'll hear about a life-death continuum that is becoming ever more apparent as new technologies facilitate resuscitations, cloning, and other interventions that blur the line between life and death. A biologist and biomedical engineer focuses on energy flow, self-reproduction, and the appearance of natural selection, while a philosopher talks about the Greek concept of *psuchê*, a life force that keeps a body together as it interacts with an external environment. Poet, Pulitzer Prize winner, and former U.S. poet laureate Louise Glück gives us something beautiful and disturbing.

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ROBERTA WHITE, NEUROPSYCHOLOGIST

THE CONTINUUM: LIFE, DEATH, SPIRIT

WHEN SOMETHING IS alive, it can die. That makes assigning life to some things easy—e.g., plants are alive, but computers are not, even though they have some characteristics that we think about when we reference living creatures, especially "intelligent" life.

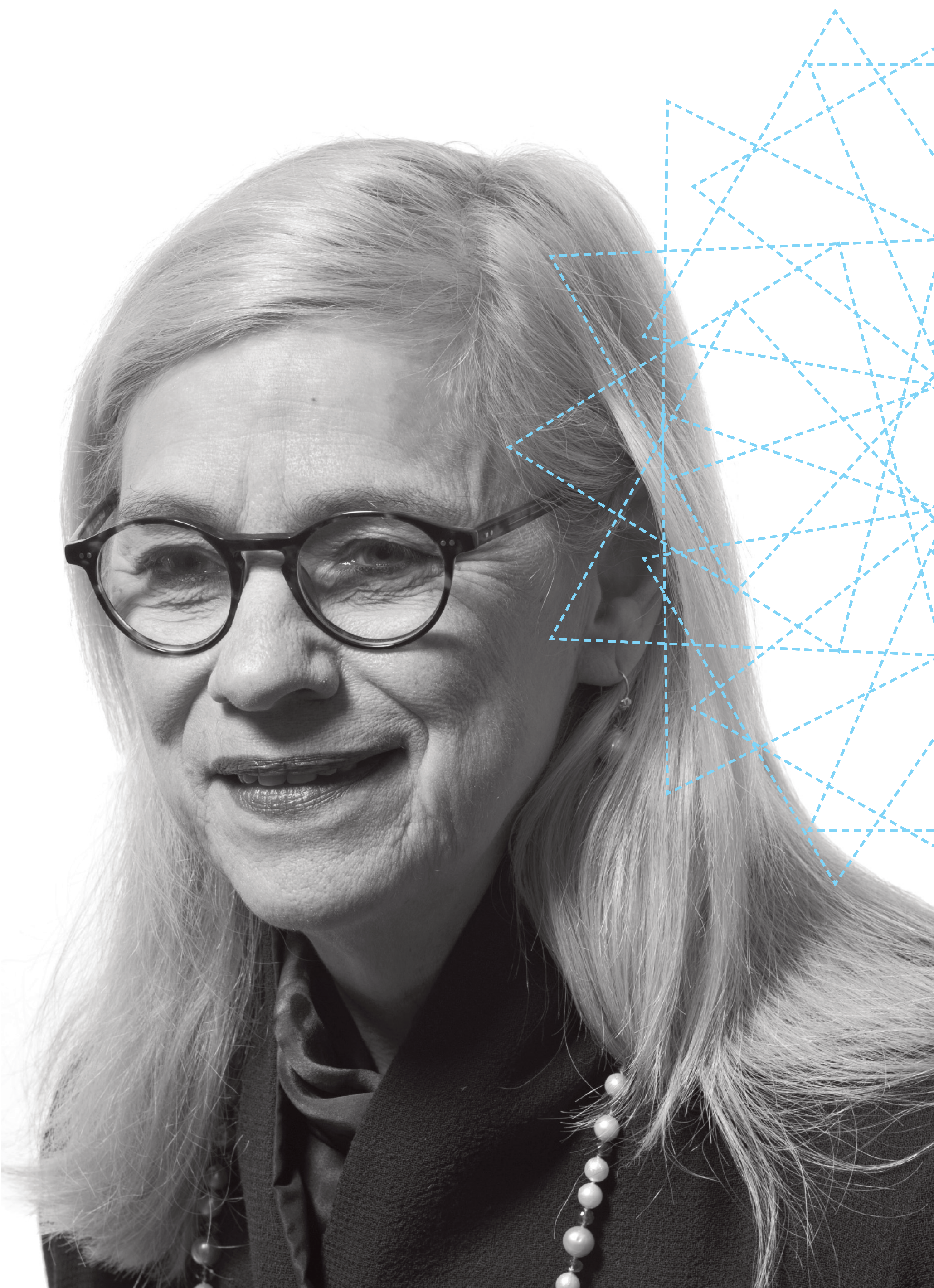
The idea of the soul, or spirit, is one of the most fascinating aspects of being alive, at least for humans and probably for other animals. When we refer to dead bodies as "remains," we are describing the absence of this characteristic of animate creatures. The unifying force that produces actions, personality traits, affective responses is gone; only a mass remains. What is this spirit? For animate creatures, this phenomenon reflects nervous system/neurotransmitter/electrical activations that work in wonderful concert. This is especially so in humans, whose consciousness allows them to ask questions about being alive, but I don't think this distinguishes "life" from "not life." I can't see how consciousness applies to plants or microorganisms such as bacteria, which I think of as being alive.

There is not a bright line between life and death:

ROBERTA WHITE is a School of Medicine professor of neuropsychology and behavioral neuroscience and a School of Public Health professor and chair of environmental health and associate dean for research.

it is a continuum. In many situations, animals are considered to be dead if respiration and cardiac function cease, but resuscitation is sometimes effected, meaning that life has either returned or the person or animal never really died. This situation was memorably described by the character Miracle Max in *The Princess Bride*, when he was asked to treat the apparently dead hero brought in by friends. "It happens that your friend here is only *mostly* dead. There is a big difference between mostly dead and all dead. Mostly dead is slightly alive." In these cases, I would argue that death had not actually occurred (at least death of the nervous system/brain). Furthermore, when people stop breathing and their hearts stop, there is a period before the body becomes cold and cannot be resuscitated that is like a twilight: facial expressions may seem appropriate and peaceful, there may be body movements, the body feels supple and warm to the touch. (Although many people think they will be afraid of the body of a loved one after the conventional signs of life have ceased, in my experience they generally are not. It is comforting and comfortable to embrace loved ones at this time in a way that is not true when warmth disappears and rigidity sets in.)

The alive-dead continuum raises other interesting conundrums. For example, zombies are mythical beings—humans who died, but through infection or some other means rise up and walk again, clearly with the reinvigoration of parts of the nervous system (brain stem). Generally, they do not act coherently. Although they may be thought of as being dead (and are often called the "walking dead"), they seem to breathe and they can be "killed." When this occurs, does something that is "alive" die a second time, or are zombies really dead, but then destroyed when they are killed off? It's also interesting to ask why such creatures fascinate us. Is it because of the life-death continuum that we carry around in our unconscious minds? There will be more issues like these as technology facilitates resuscitations, cloning, and other interventions that illuminate the continuum between life and death. For example, when people are cryogenically frozen after death—and eventually revived when and/or if the technology becomes available—were they dead while frozen or simply alive in some sort of suspended state? Similarly, it will be interesting to see if robots will eventually seem alive to us when they become sufficiently sophisticated (as in *Blade Runner*). And they will.



DAVID ROOCHNIK,
PHILOSOPHER

BODY PARTS PLUS SOUL PLUS ENERGY

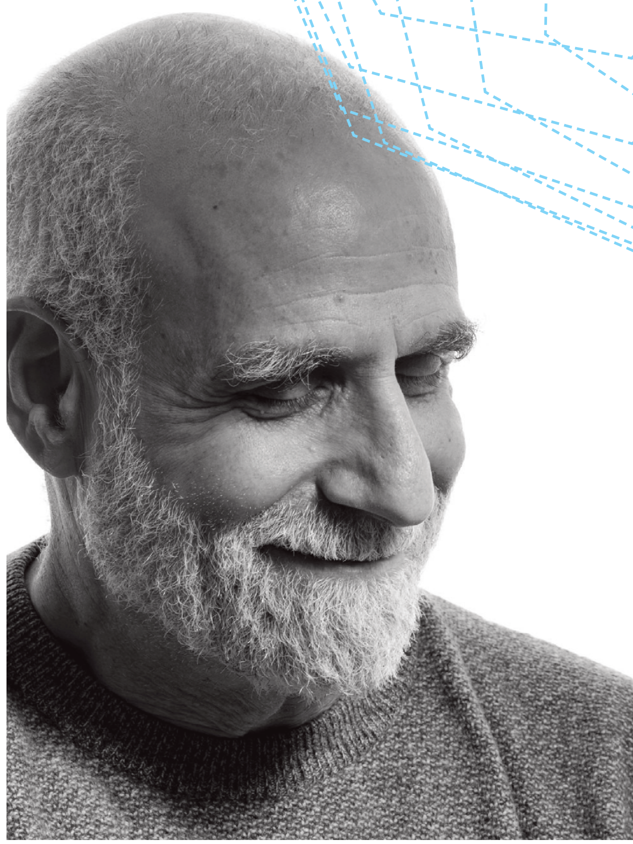
NO PHILOSOPHER UNDERSTANDS or appreciates life better than Aristotle. He invented what we now call "biology," which is derived from the Greek words *bios* (life) and *logos* (rational explanation), and about a quarter of his massive collection of writings is devoted to the study of animals. But in addition to his groundbreaking empirical work in the biological sciences, he also thought long and hard about the philosophical question we are asking here: what is life? What follows is the briefest of sketches.

The first step Aristotle takes toward answering our question is to offer a simple observation: the things that we see out there in the world aren't all the same. Some, like plants and animals, are alive, while others, like rocks and water, are not. So far, so good. But the story gets complicated fast. For every living being is a material entity and so has parts that by themselves are not alive. An animal's body, to take Aristotle's favorite example, contains water, which by itself is not alive.

So our question—what is life?—is better formulated as, how is it that a conglomeration of material elements, which on their own are not alive, is alive? What is responsible for that?

This question already

DAVID ROOCHNIK is a College of Arts & Sciences professor and chair of philosophy.



implies something important: to be alive is to be more than a collection of material elements. Imagine seeing the corpse of an animal that has very recently died. With the one massive exception of no longer moving (except when something else moves it), it looks just like the living animal. For it is composed of the same elements as the living animal. But it is not alive. As a result, the corpse will decompose soon, and its elements will disperse. For an animal to be alive, then, means that it can hold itself together and maintain its unity even as it undergoes continual change.

To reformulate this same point: there's no such thing as a dead animal. When an animal dies, the body that remains, which for a short while is made of the same stuff, is no longer an animal. It's just a cluster of material elements.

Being an animal, then, cannot be fully explained simply by listing its material parts. Something else is required: that which is responsible for keeping the parts together. But what is that? Aristotle's answer, which to a contemporary audience will likely seem completely wrong, is the "soul." This English word is the traditional, but terribly misleading, translation of the Greek *psuchê* (the root of "psyche" and "psychology"). *Psuchê* itself derives from the verb *psuchô*, "to breathe," and means "breath of life" or "life force." What it does not mean is what the word "soul" typically suggests to us: a nonmaterial substance that is somehow separate from the body. Instead, the *psuchê* is the continuous "activity" of a living body keeping itself together as it interacts with an external environment. It is the mutually enabling "work" of the body's parts that maintains the animal's unity over time. Aristotle's key word here is *energeia*, the ancestor of "energy."

The *psuchê* is the *energeia* of a living body. As such, it is inseparable from the body. But, and for Aristotle this is the crux, even if it is not separable from the body, the *psuchê* is different from it. An animal is not just a bunch of material elements. Instead, it is a dynamic whole that is more than the sum of its parts. Of course, without its parts it cannot live, but it is more. It is alive.

It's a terrible mistake, then, to think that living beings simply are equivalent to their bodies. Indeed, to think this, especially when it comes to studying the human animal, invites catastrophe.

WEB EXTRA Read what BU ethicist George Annas has to say at bu.edu/bostonia.

TOM BANIA,
ASTROPHYSICIST

BLENDED LIFE: 60 PERCENT HYDROGEN, 25 PERCENT OXYGEN, 10 PERCENT CARBON, AND 2 PERCENT NITROGEN

WHAT IS LIFE? It seems pretty clear that life on Earth arose from a combination of natural chemical processes in the early oceans, augmented by cometary material falling from the sky. Everything in the universe is made of the same stuff—the 92 atomic elements on that periodic table in your high school chemistry lab.

If you ask, however, what things are made of, you find that life as we know it on Earth is special and distinct. If you were to put the entire universe in a blender and count its atoms, you would find that 93 percent of them are hydrogen—the simplest element of all—and 6 percent are helium, the next simplest. All of the other 90 atomic elements together comprise only one percent of the universe.

The blended planet Earth's recipe, however, is quite different; its two most abundant atomic elements are oxygen (47 percent) and silicon (28 percent).

Living things are unlike anything else in the universe. Blended life is made up of 60 percent hydrogen, 25 percent oxygen, 10 percent carbon, and 2 percent nitrogen, with smaller amounts of calcium, phosphorus, and sulfur. If you are an animal, your recipe is seasoned with a tad of iron from your blood's hemoglobin, and if you are a plant, your seasoning is magnesium from your chlorophyll. So life is very different from the nonliving universe—it has a distinctly different recipe.

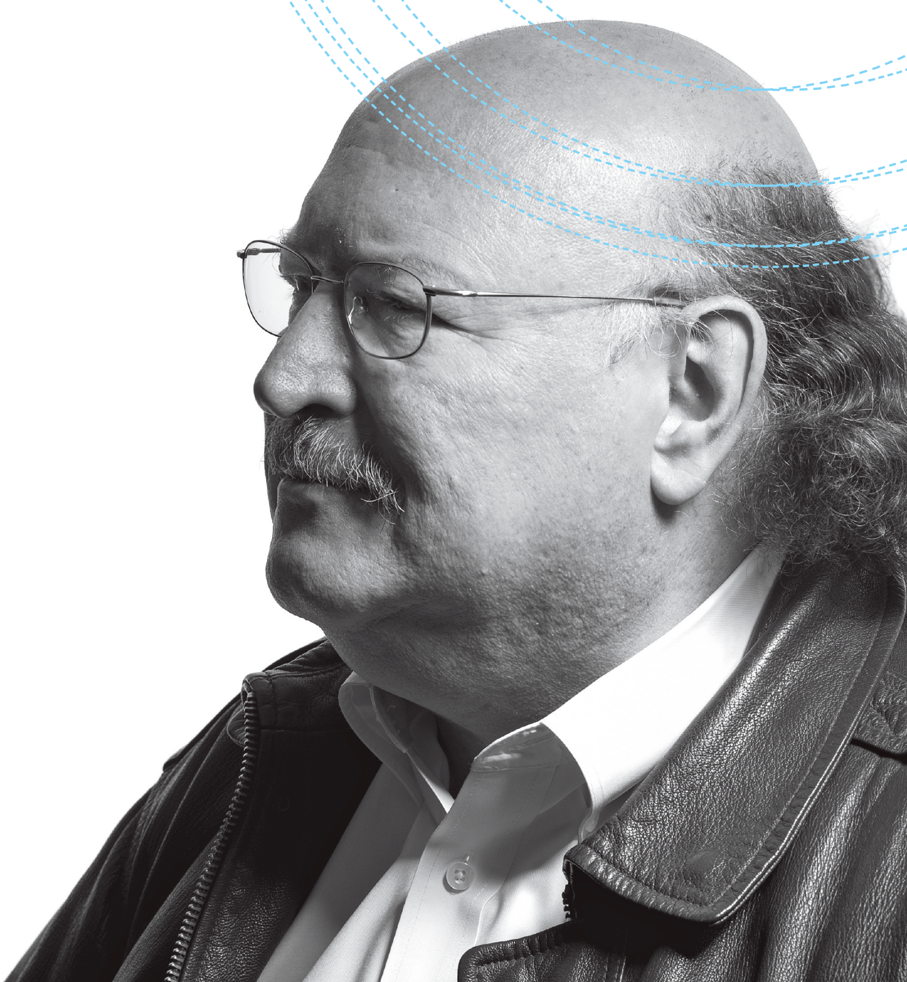
What is a human being? A walking bag of saltwater with organic molecules on the inside. Some of those complex molecules, proteins, are thousands upon thousands of atoms long, and they do very specialized things. And it's hard to see how they could have assembled from simple molecules in primordial oceans. It might have been accelerated by more complex molecules delivered by meteors.

The universe will also create complex organic molecules in space, and we see them in the gas between the stars. Here on the surface of the Earth, if you make organic chemical systems complex enough, you get living systems, and we can agree that two important things these living systems do is eat and reproduce. There are something like a half dozen chemical ways that living things extract and store the energy they need to be alive.

And we all know the role that chemical DNA plays in reproduction. The biochemistry of Earth's living systems is almost certainly not a unique solution to the challenge of becoming (and staying) alive, but it is compelling evidence to me that, at least when they start, organisms are going to be chemical-based and will be the product of organic chemistry.

I would be astonished if extraterrestrial life had DNA that was the same as ours using exactly a three-base sequence for codons and things like that. In fact, if a life-form passed its genetic message down in ways that were different from ours, it would be proof that that life-form was extraterrestrial.

TOM BANIA is a College of Arts & Sciences professor of astronomy and a founding member of the Institute for Astrophysical Research. He studies the interstellar medium of the Milky Way and other galaxies.



DANIEL SEGRÈ, BIOLOGIST

A SELF-REPRODUCING AND EVOLVING CELL

IMAGINE PLANET EARTH before life: water, rocks, volcanoes, and lifeless landscapes. Now, imagine it millions of years later, increasingly filled with tiny globules capable of growing, self-replicating, and evolving—the first cells. How did this transition occur? How did the laws of physics and chemistry—the same laws that govern the world today—transform the inanimate matter of early Earth into our unicellular ancestors? I think of this as one of the most fascinating open questions in science—at the crossroads of physics, chemistry, and biology. Multiple bits of evidence suggest that the first living cells emerged on our planet around 3.8 billion years ago. To put this in perspective, if the whole history of life, from those early stages, were rescaled to one year, the rise of modern humans would occupy just the last half hour.

The precise details of how life started may be lost forever in the meanders of history. This does not mean that we cannot understand what aspects of chemistry and physics make life possible. A lot of research on the origin of life focuses on understanding the mechanisms that could have given rise to the basic molecular players essential for life as we know it today (such as amino acids, which combine to form proteins, nucleotides that make up genomic DNA, as well as DNA's versatile cousin, RNA). This is very important. However, even if we put a lot of these molecules together in a test tube, life will not emerge from it. In addition, it is not obvious that the molecules that compose present-day life are a prerequisite for the emergence of life in general. Whether this is the case can significantly affect the way we search for life elsewhere in the universe. To make an analogy at the human scale, imagine that we want to learn about the history of flight. If we focus solely on the materials that make modern airplanes, we would completely miss the very early stages of that endeavor.

Hence, I think that in order to understand the transition from an early chemical mixture to the first living cell, we need to gain a much better understanding of the fundamental physico-chemical processes that

DANIEL SEGRÈ is a College of Arts & Sciences associate professor of biology and a College of Engineering associate professor of bioinformatics and biomedical engineering.

make life possible. Living systems have to be far from thermodynamic equilibrium—i.e., they require a flow of energy to stay organized. Lack of an energy input results in disorder (very much like what happens in a typical household!). One of the key properties made possible by this energy flow is the capacity of living systems to self-reproduce. A subtle and often debated aspect of self-reproduction is that no single molecule ever has to self-replicate in order for a cell to reproduce, or for life to begin. Rather, one can think of cellular life as a collective phenomenon, in which many different types of molecules help one another replicate in an intricate, but well-organized, network of chemical reactions. Inheritance and variability, essential for establishing an evolutionary process, could be a natural outcome of the dynamics of these complex networks, even prior to the advent of genomes.

Understanding all these processes and how they relate to one another will constitute a key component of our path toward understanding life and its origin. It will require the cooperation of scientists from different disciplines and the combination of theory and experiment. One should keep in mind that the early appearance of living cells is just the first step in a long series of fascinating transitions in the history of life. For example, we still know very little about the conditions and processes that gave rise to complex multicellular life, without which we would not be here, searching and contemplating.

LOUISE GLÜCK, POET

THRUSH

CORBIS

Snow began falling, over the surface of the whole earth.
That can't be true. And yet it felt true,
falling more and more thickly over everything I could see.
The pines turned brittle with ice.

This is the place I told you about,
where I used to come at night to see the red-winged blackbirds,
what we call *thrush* here—
red flicker of the life that disappears—

But for me—I think the guilt I feel must mean
I haven't lived very well.

Someone like me doesn't escape. I think you sleep awhile,
then you descend into the terror of the next life
except

the soul is in some different form,
more or less conscious than it was before,
more or less covetous.

After many lives, maybe something changes.
I think in the end what you want
you'll be able to see—

Then you don't need anymore
to die and come back again. ■

LOUISE GLÜCK, a visiting professor in BU's Creative Writing Program, won the Pulitzer Prize in Poetry in 1993. She is a former U.S. poet laureate and a recipient of the National Book Critics Circle Award, among many other awards.