5

LIFE & PURPOSE

1210L

BIG HISTORY PROJECT

LIFE & PURPOSE

A BIOLOGIST REFLECTS ON THE QUALITIES THAT DEFINE LIFE

By Ursula Goodenough

What's the difference between nonlife and life? To answer this question, we first need to define life. I'll lay out what are to me the key hallmarks of life, and then offer a response that flows from such an understanding.

A key concept is that every organism is a self, a being. To be a “self” is to engage in two fundamental activities: self-generation and self-maintenance.

Self-generation

Self-generation entails the making of a self. If you’re a single-celled organism like a yeast, this involves starting out small, growing large, and dividing into two small daughter-yeasts that start the process again. If you’re a multicelled organism like a human, this involves starting out as a single fertilized egg, developing from an embryo to a fetus, and then taking the path from newborn to old age.

In all organisms on our planet today, the key players in self-generation are proteins. When a particular protein is made, it folds up into a particular shape, with crevices and bumps — something like a jigsaw-puzzle piece in three dimensions. These shapes allow proteins to do two major activities.

The first is to interact with other proteins, with the bumps fitting precisely into the crevices, to form the thousands of different kinds of chemical structures that make up a cell. Most parts of a cell are constructed from proteins, including the filaments that act as cellular skeletons, the channels that let ions in and out of the cells, and the receptors that let the self know what’s going on in the environment.

The second activity of proteins is to serve as enzymes, which allow chemical reactions inside the cell to take place with remarkable efficiency and accuracy. Again, shape is the key. The bumps and crevices bring together the participants in a chemical reaction and ensure that they form the proper kinds of chemical bonds with one another.

Self-maintenance

Critical to self-generation is obtaining the molecules and the energy that the self needs to run the store. One strategy is to use photosynthesis, turning the Sun's light energy into food. The second is to ingest molecules that are made as a consequence of photosynthesis — that is, to eat — and then break them down, using the energy released to drive self-generation. Here again, the shapes of enzymes are critical, but instead of controlling the formation of chemical bonds as in self-generation, they deftly supervise the breaking of chemical bonds, coupling this activity with the formation of energy-rich molecules like ATP (adenosine triphosphate) that keep the cell going.

Self-maintenance also entails self-protection, avoiding environmental hazards, predators, and disease.

Every organism is instructed

All the proteins we've been thinking about are encoded in genes embedded in DNA molecules. Each gene specifies the amino-acid sequence of a particular protein, and that sequence then defines how the protein will fold up into its functional shape.

The full set of genes necessary to pull together a self-generating and self-maintaining self is called a "genome." A yeast genome and a human genome have many genes in common, notably those concerned with the universal project of self-maintenance, and many others that are distinctive. Daughter organisms inherit copies of genomes from parent organisms, allowing that kind of organism to continue and spread.

Embedded in the organization of genomes is the capacity to express certain genes, and hence certain proteins, on some occasions and not others. When it's time to copy DNA into daughter molecules, the genes encoding the DNA-copying enzymes are "switched on." When the copying process is completed, these genes are "switched off." When it's time for you to make red blood cells, genes encoding the hemoglobin protein are switched on in certain bone-marrow cells but remain switched off in most of the cells in your body. Thus a genome isn't just a collection of genes; it functions continuously to instruct self-generation and self-maintenance.

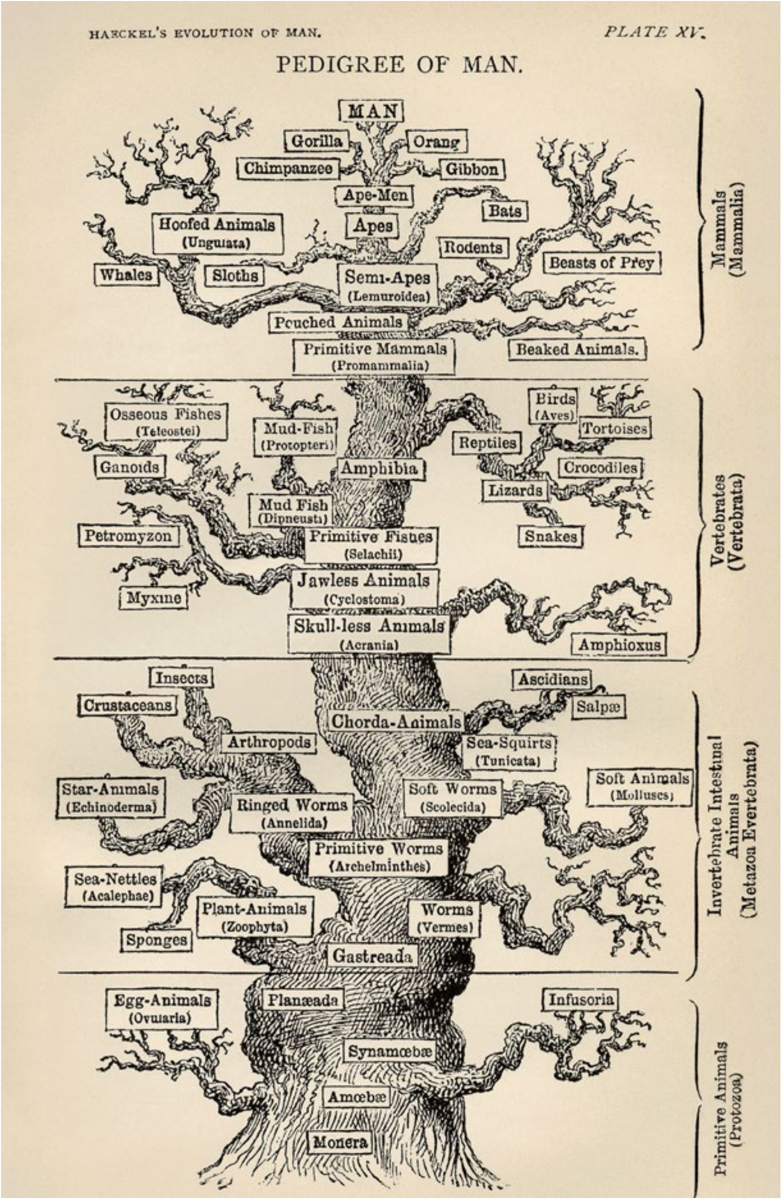
Every organism can evolve

Although DNA is copied with remarkable accuracy, mistakes sometimes happen, giving rise to mutant genes that encode variant amino-acid sequences and hence give rise to proteins with variant shapes. Also occurring are "mutations" that change the timing or magnitude of protein production.

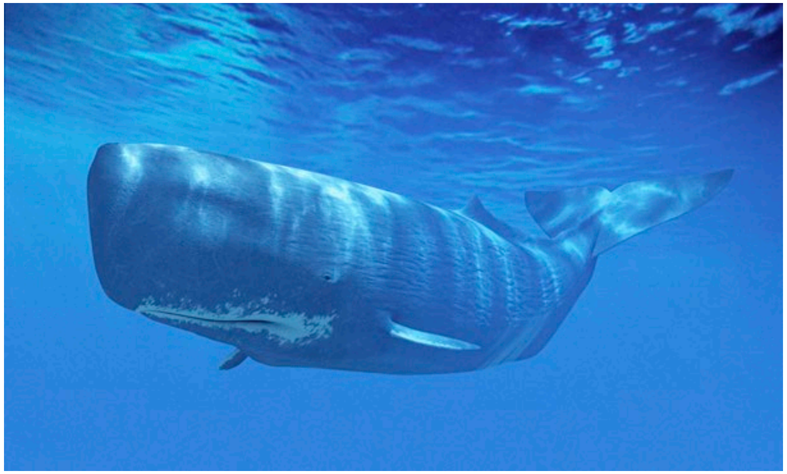
The mutation may have no effect, at least in the short term, in which case the mutant daughter may self-organize and self-maintain just like the parent. At the other extreme, it may have disastrous consequences on self-organization and self-maintenance, and the daughter will not survive.

The most interesting mutations are those that generate instructions for a viable daughter that is somewhat different from its parent. For example, a parent duck may have delicate foot webbing while the webbing of a mutant daughter may be extra-thick. What happens next is totally dependent on environmental context. If the ducks hang out on mudflats, the mutant feet may allow for surer footing, hence better opportunities for feeding and fleeing predators, and the thick-footed trait will likely spread into future generations; if the ducks live in grasslands, the mutant feet may slow things down and the trait will be less likely to spread.

What I've just described is Darwinian evolution: inherited variations, coupled with natural selection. The ability of living organisms to evolve has generated the spectacular biodiversity that surrounds us, and without it, we humans would never have shown up.



Ernst Haeckel's 1879 illustration of the "tree of life" shows humans as the pinnacle of evolution, a common view among early evolutionists



Every organism has purpose

So, with this sense of what life is, can we come up with a single characteristic that distinguishes life from nonlife? Is there one towering difference between a mountain and a whale? After all, both are made of molecules. Both engage in chemistry. Both change through time.

For me, the most interesting single generalization is that organisms are purposive whereas nonlife is not. Organisms are about something, for something: muscles are for movement; eyes are for seeing. Organisms have goals. The short-term goal is to self-generate and self-maintain in a given environmental context. The long-term goal is to pass genome copies on to offspring, a goal that succeeds only if self-generation and self-maintenance succeed. Mountains are splendid, to be sure, but in the end they aren't goal directed. They just are.

Taking this perspective, one could say that when life showed up on Earth, something completely new showed up: the emergence of purpose. Whether life, and hence purpose, exists anywhere else in the Universe is unknown and may remain a mystery. Meanwhile, we can enjoy and revel in the astonishing purposiveness that surrounds us here on Earth.

Ursula Goodenough

Ursula Goodenough is a professor of biology and a research leader at Washington University in St. Louis, Missouri. She has devoted years of research to the flagellated green soil alga called *Chlamydomonas reinhardtii*. Goodenough has also written or coauthored numerous books, including *The Sacred Depths of Nature* (1998). Goodenough recently initiated research work on biogenesis in *Chlamydomonas*, contributing to an international effort to produce algal biodiesel as an alternative energy source.

Image credits

Phytoplankton off Vancouver Island,
courtesy of Jeff Schmaltz, MODIS Land Rapid Response Team
at NASA GSFC

Japanese macaques in Jigokudani Onsen, Nagano, Japan
© Radius Images/CORBIS

A sperm whale
© Denis Scott/CORBIS

The Matterhorn, one of the highest peaks in the Alps
© Dirk Beyer

NEWSELA

Articles leveled by Newsela have been adjusted along several dimensions of text complexity including sentence structure, vocabulary and organization. The number followed by L indicates the Lexile measure of the article. For more information on Lexile measures and how they correspond to grade levels: http://www.lexile.com/about-lexile/lexile-overview/

To learn more about Newsela, visit www.newsela.com/about.

The Lexile® Framework for Reading
The Lexile® Framework for Reading evaluates reading ability and text complexity on the same developmental scale. Unlike other measurement systems, the Lexile Framework determines reading ability based on actual assessments, rather than generalized age or grade levels. Recognized as the standard for matching readers with texts, tens of millions of students worldwide receive a Lexile measure that helps them find targeted readings from the more than 100 million articles, books and websites that have been measured. Lexile measures connect learners of all ages with resources at the right level of challenge and monitors their progress toward state and national proficiency standards. More information about the Lexile® Framework can be found at www.Lexile.com.