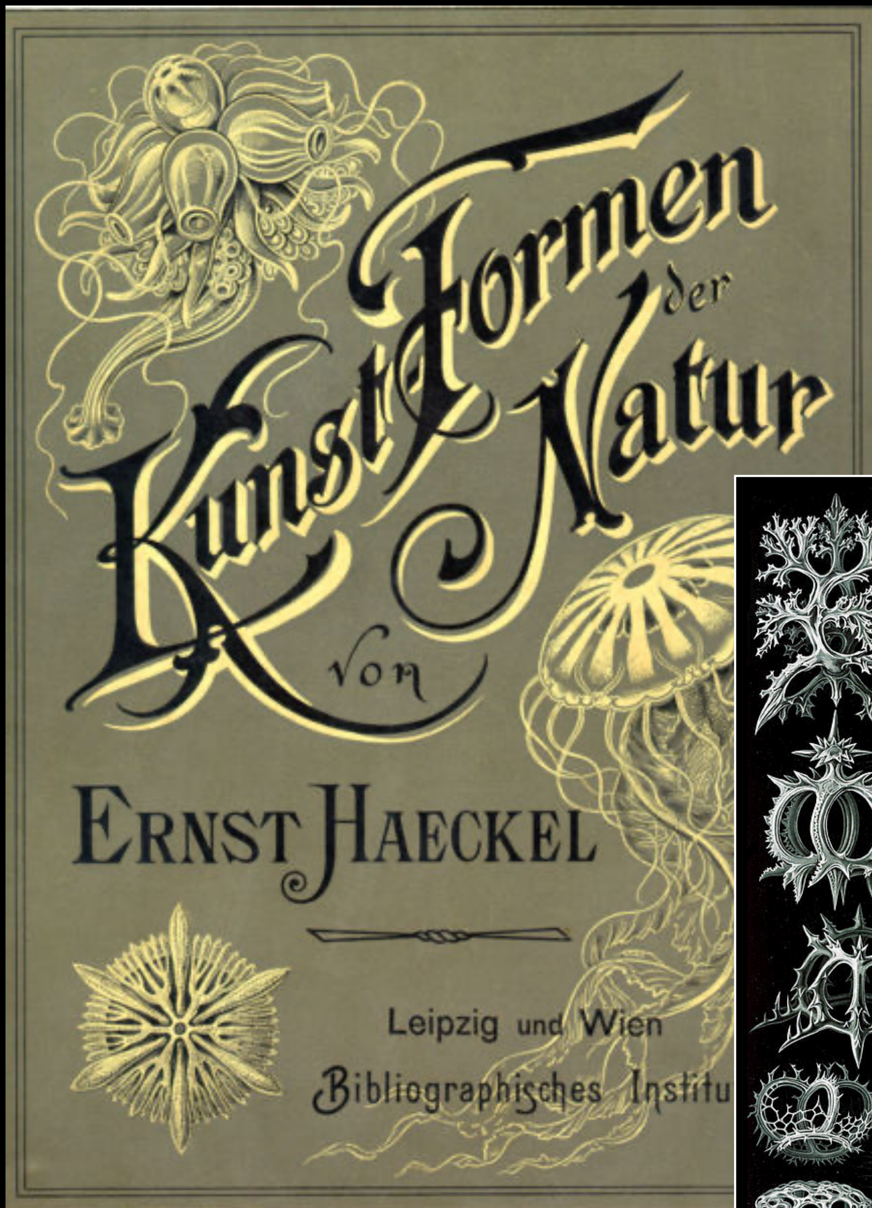
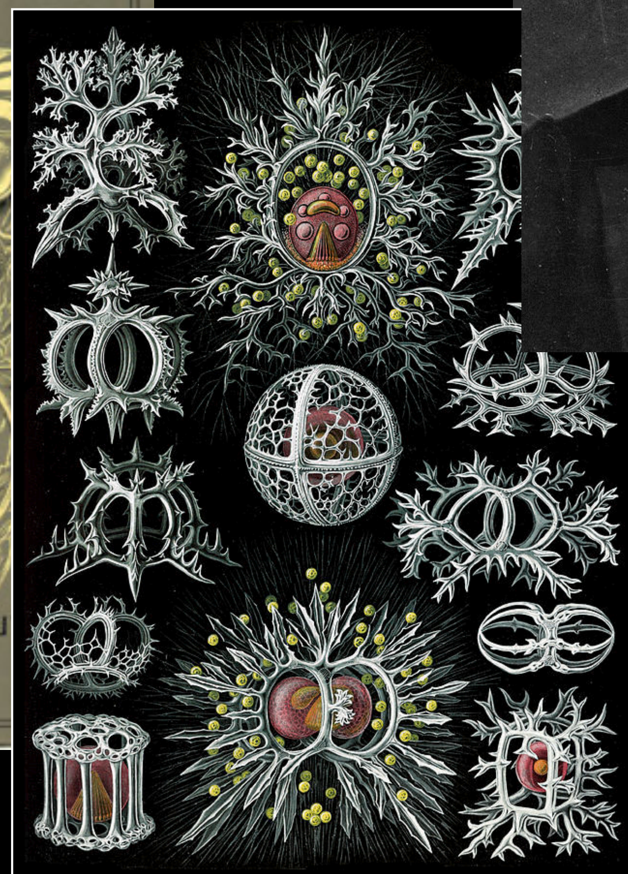
21A.303J / STS.060J
Anthropology of Biology
Spring 2022

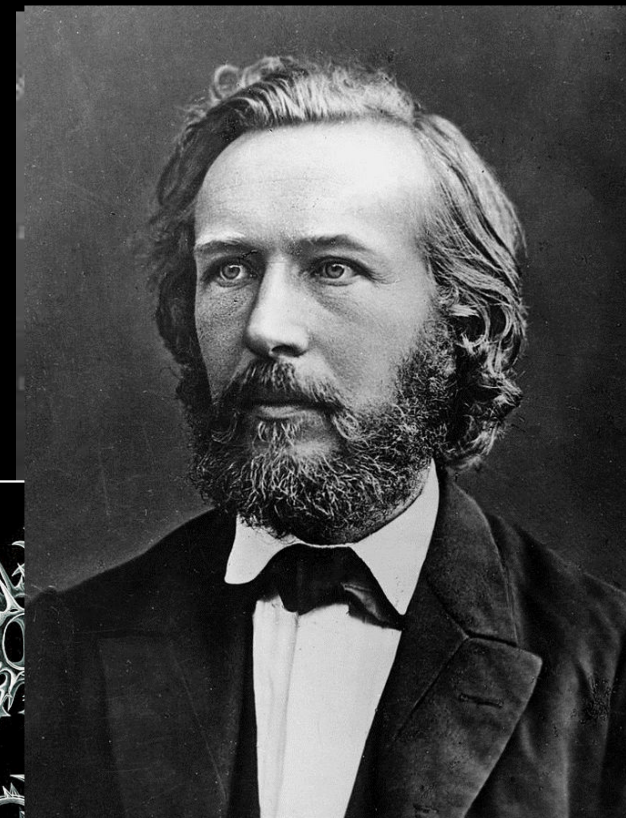
Professor Stefan Helmreich

Course Description

If the twentieth century was the century of physics, the twenty-first has become the century of biology. This subject examines the cultural, political, and economic dimensions of biology in the age of genomics, biotechnological enterprise, biodiversity conservation, pharmaceutical bioprospecting, synthetic biology, global pandemic, and more. Although we examine such social concerns as genetic modification and reproductive rights, this is not a class in bioethics, but rather an anthropological inquiry into how the substances and explanations of biology — increasingly cellular, molecular, genetic, viral, and informatic — are changing, and with them broader ideas about the relationship between "nature" and "culture." Looking at such scientific forms as cell lines, CRISPR, and epidemiological models, and drawing upon primary sources in biology, social studies of the life sciences, and literary and cinematic materials, we rephrase Erwin Schrödinger's famous 1944 question, "What Is Life?" to ask, in the 2000s, "What Is Life Becoming?"

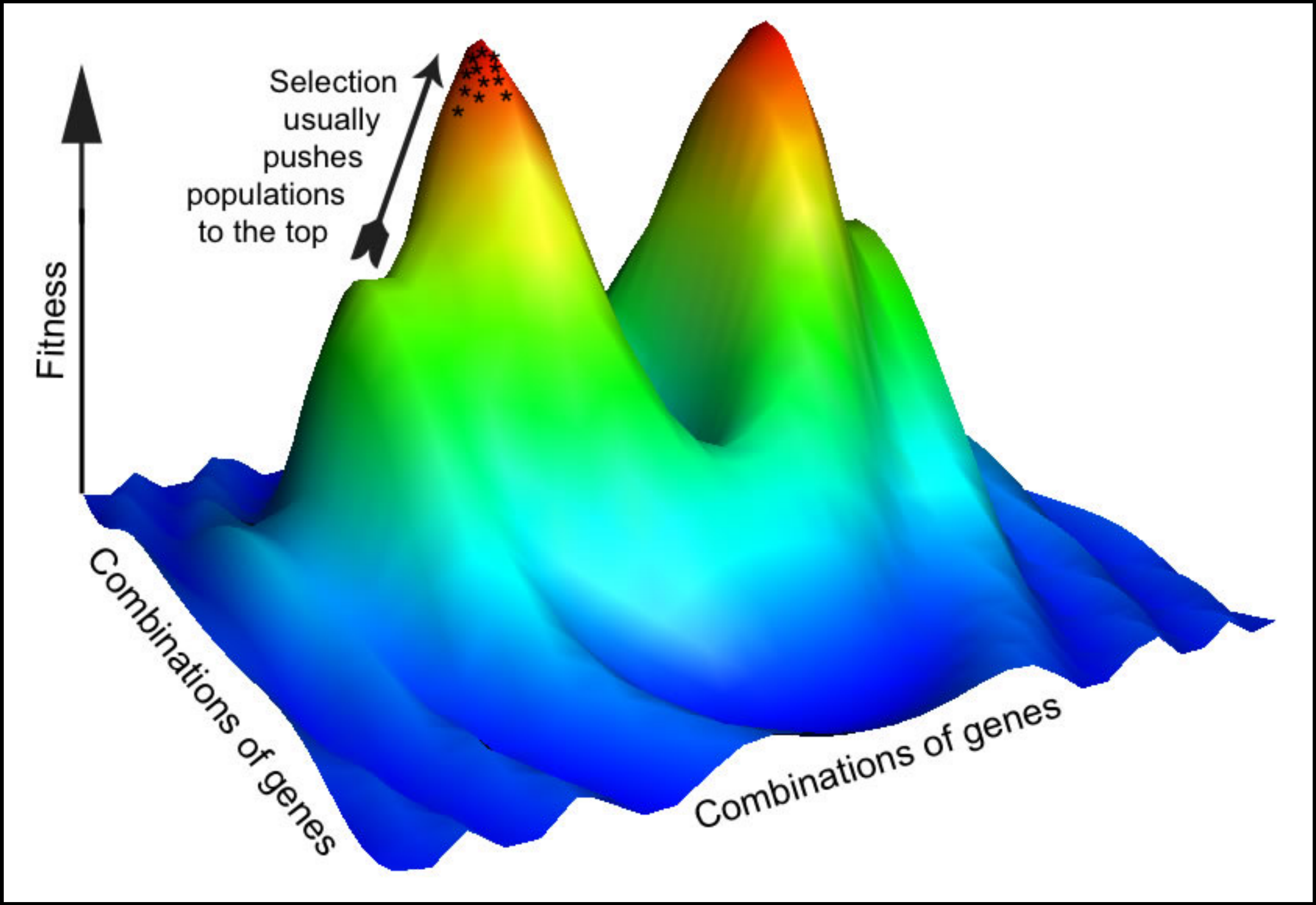


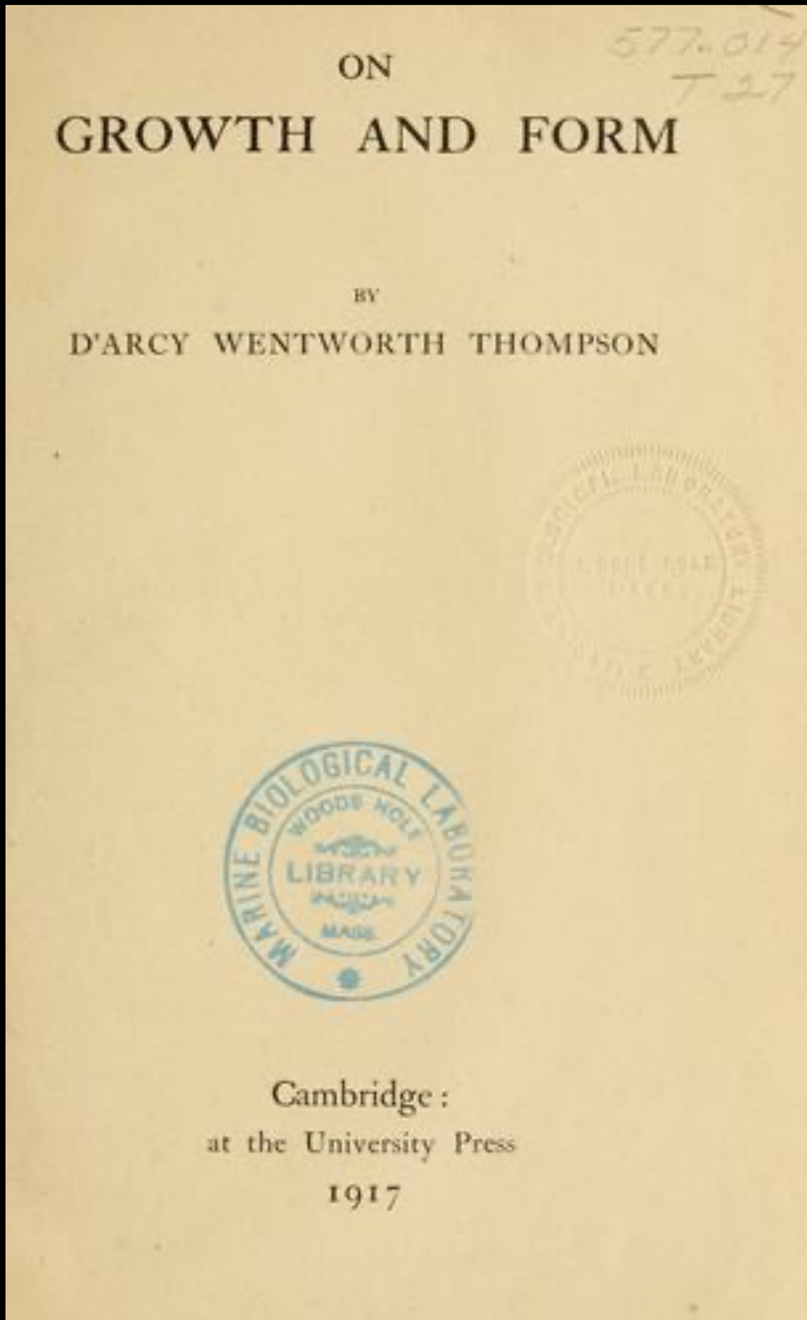




Ernst Haeckel
(1834-1919)

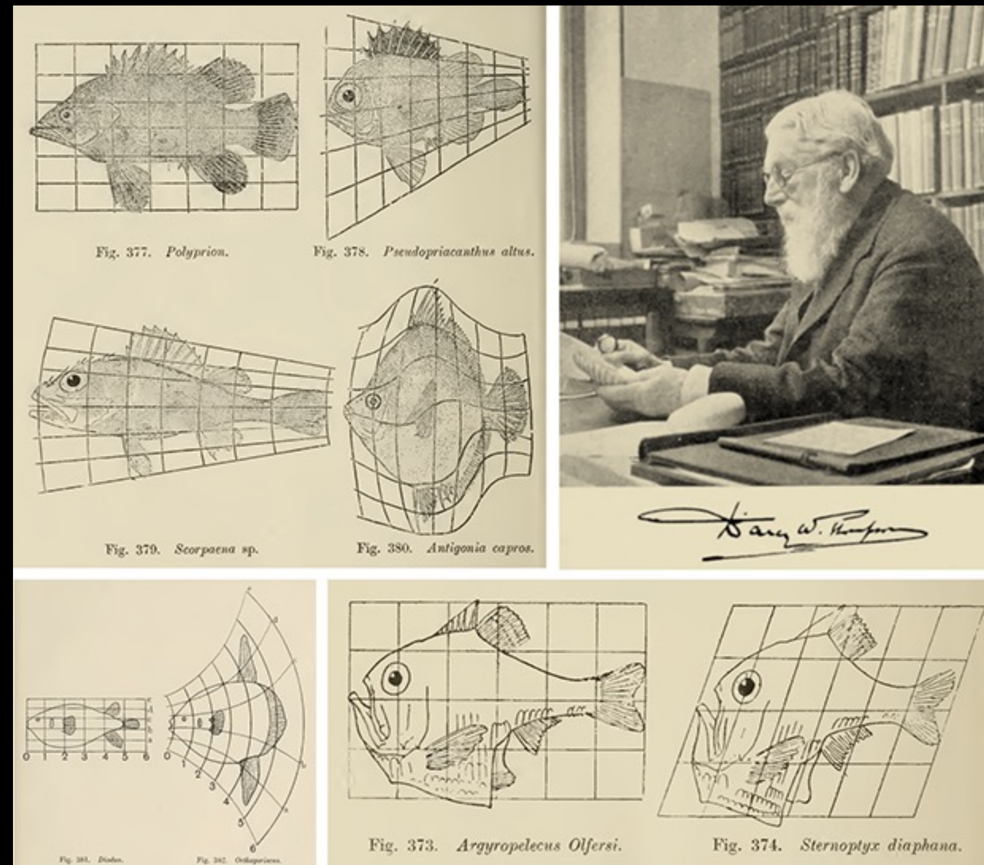
A fitness landscape, mapping abstract space of possible adaptation



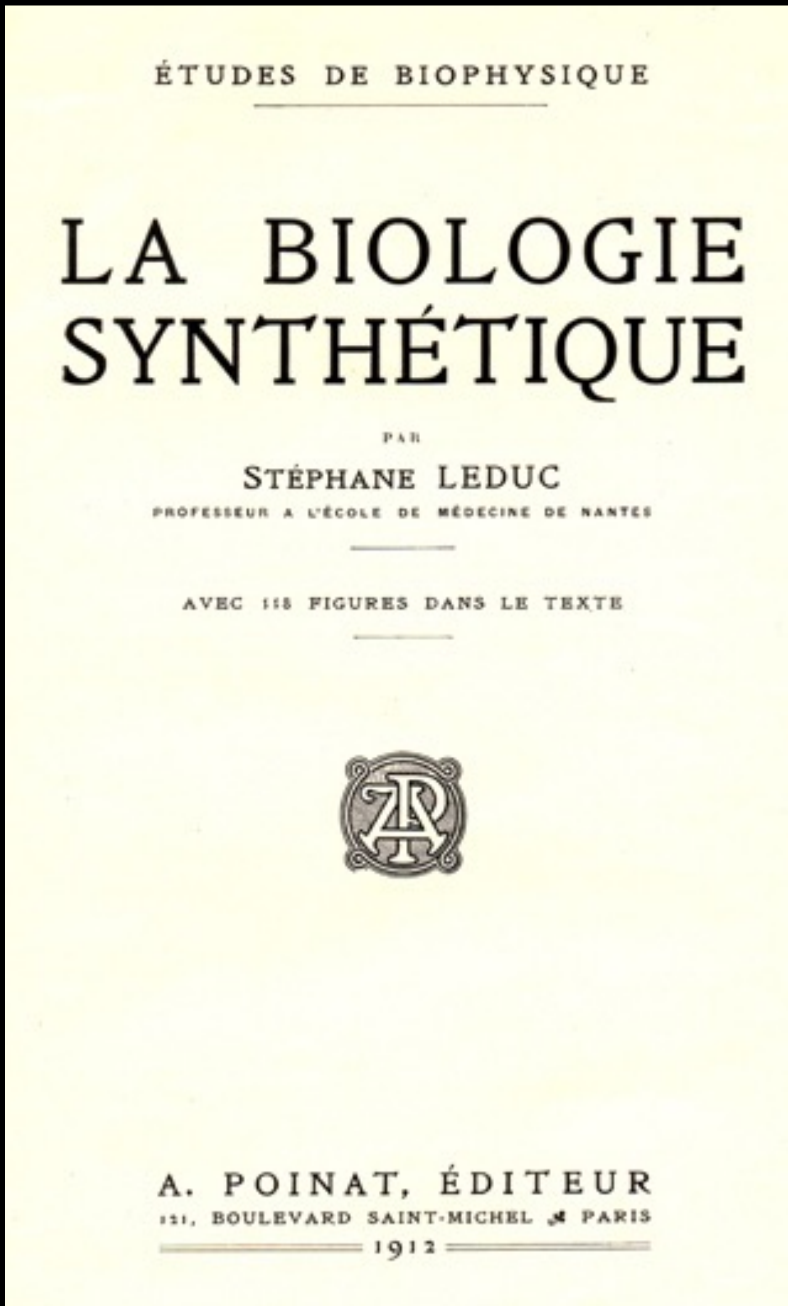

ON
GROWTH AND FORM

BY
D'ARCY WENTWORTH THOMPSON

Cambridge:
at the University Press
1917



D'Arcy Wentworth Thompson (1860-1948)



ÉTUDES DE BIOPHYSIQUE

LA BIOLOGIE SYNTHÉTIQUE

PAR

STÉPHANE LEDUC

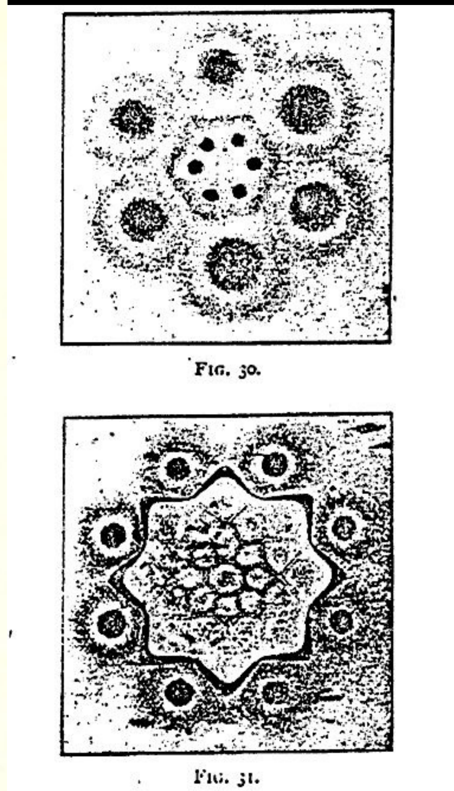
PROFESSEUR A L'ÉCOLE DE MÉDECINE DE NANTES

AVEC 118 FIGURES DANS LE TEXTE

A. POINAT, ÉDITEUR

121, BOULEVARD SAINT-MICHEL PARIS

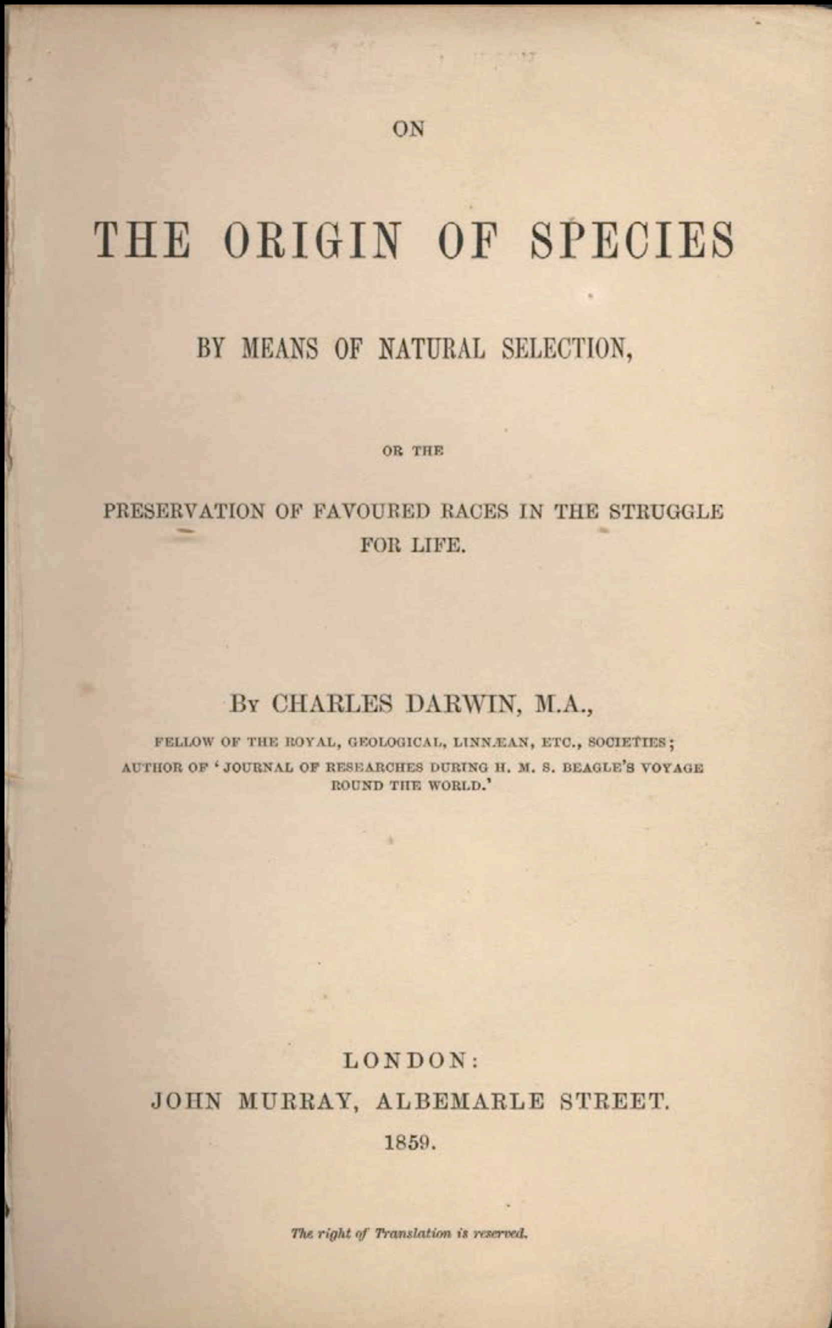
1912



Photographs of artificial cells resulting from molecular attractions and repulsions in a liquid.

Stéphane Leduc
(1853-1939)

Life is "conditioned by form, that is, the external, internal and molecular forms of the living being."



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

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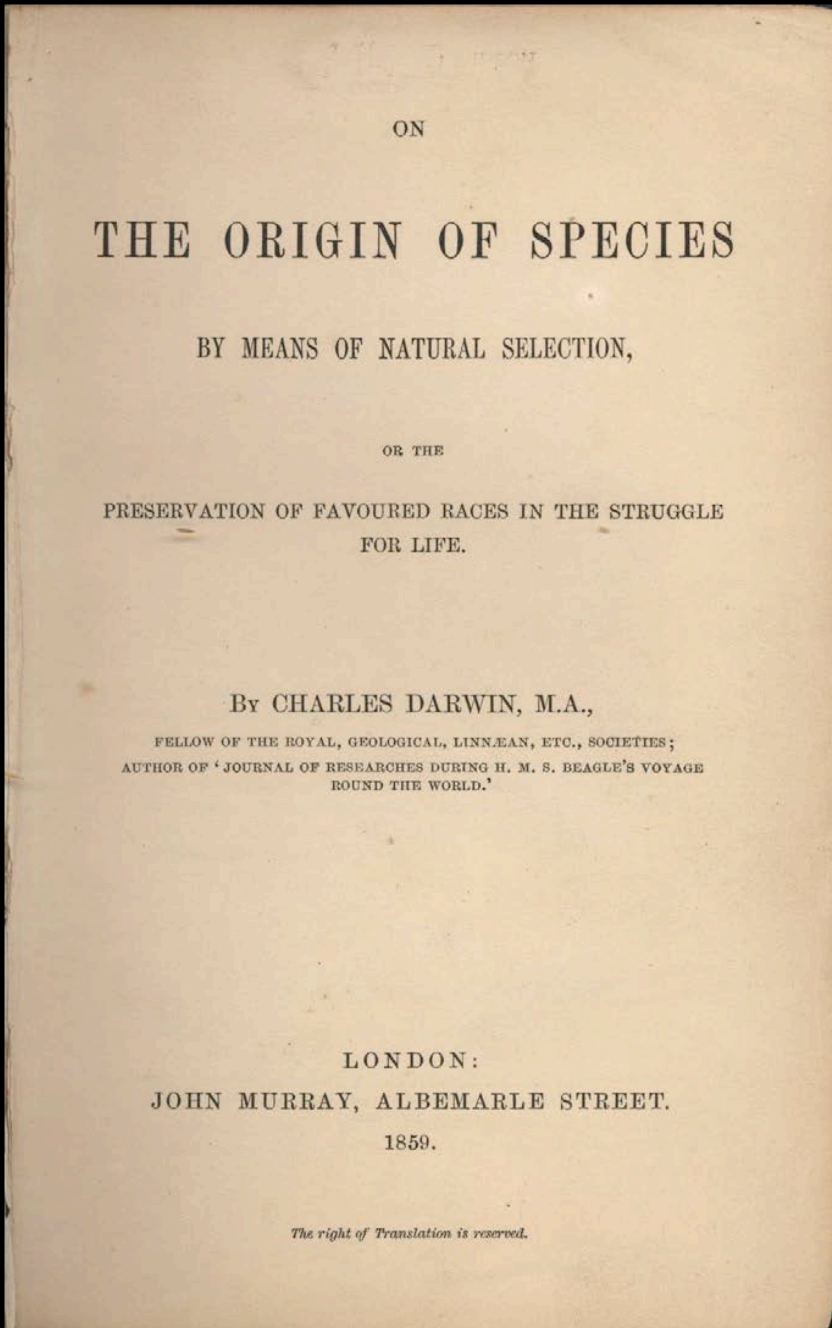
Charles Darwin (1809-1882), painted by one of his children on an envelope



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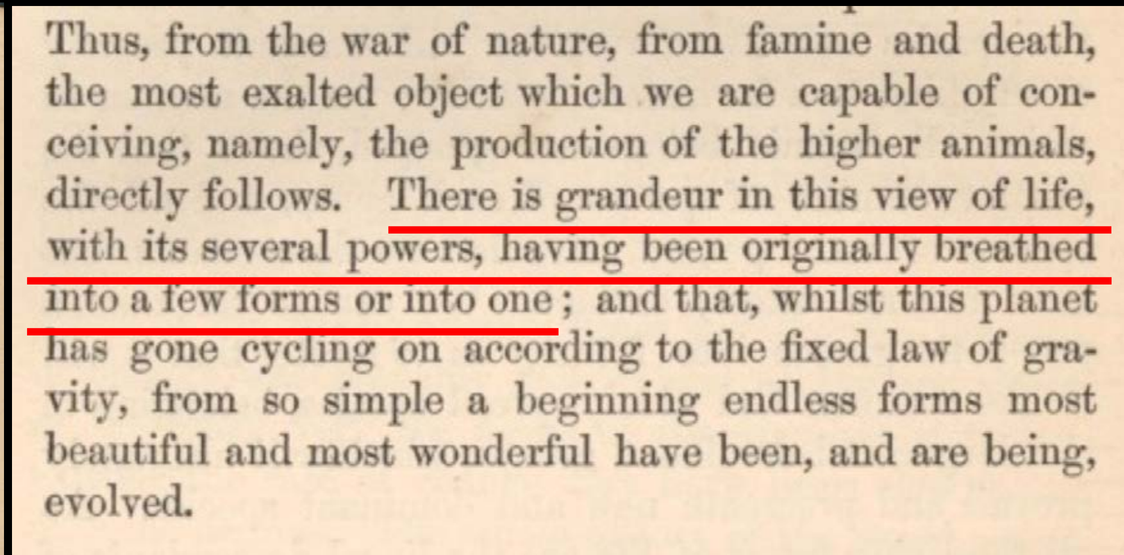

Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.

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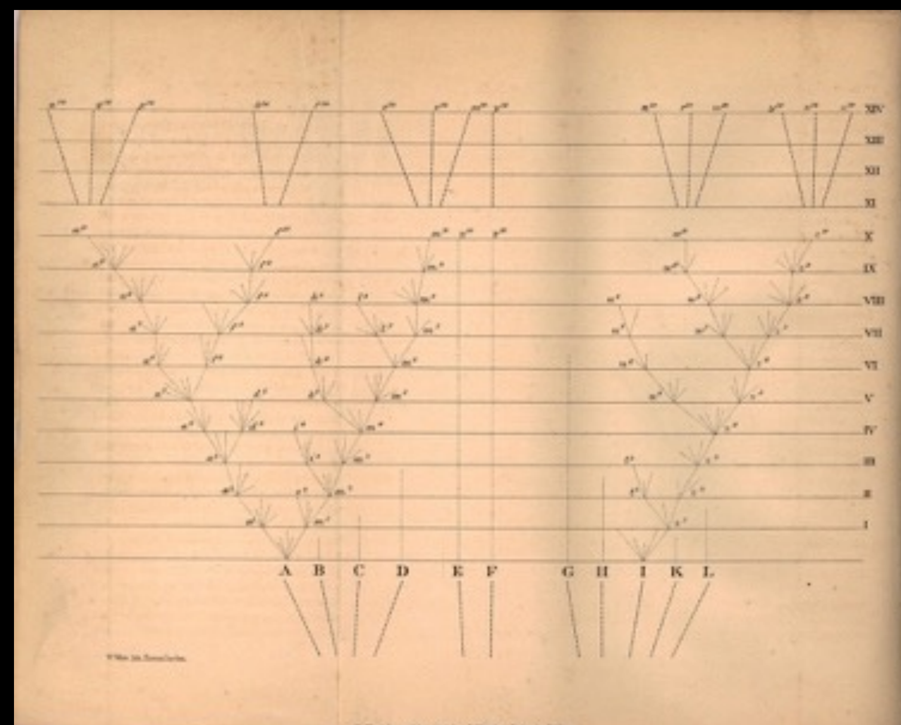
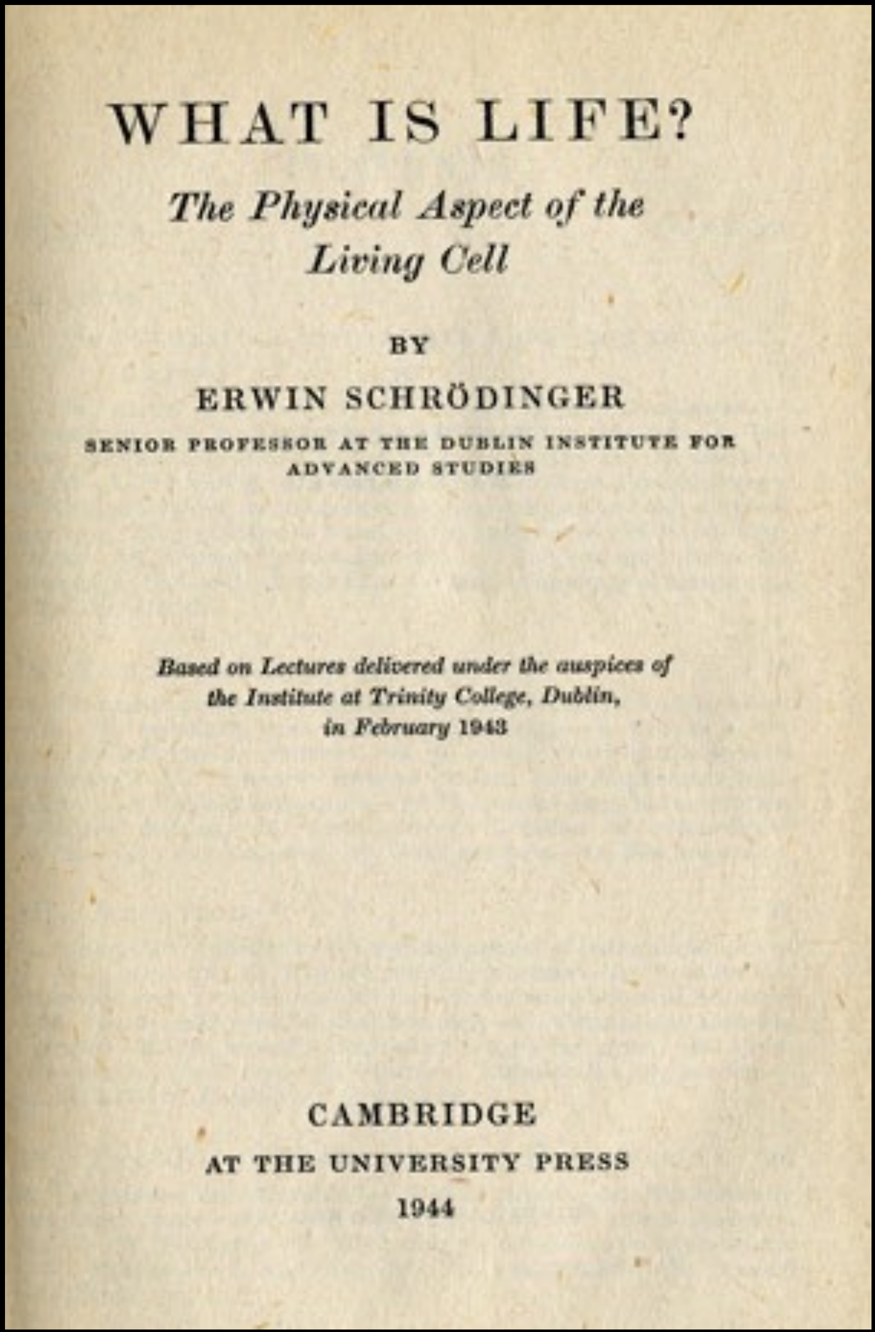
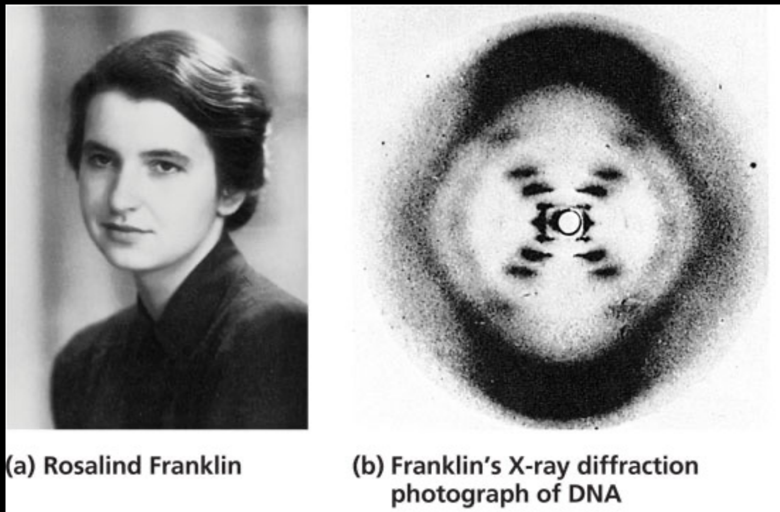




Erwin Schrödinger
(1887-1961)

"The chromosome structures are at the same time instrumental in bringing about the development they foreshadow. They are code law and executive power, or to use another simile, they are the architect's plan and the builder's craft in one"



Rosalind Franklin and her X-ray diffraction image of DNA, 1952

James Watson and Francis Crick with their DNA model at the Cavendish Laboratories in 1953.

No. 4809 December 30, 1961 NATURE 1227

GENERAL NATURE OF THE GENETIC CODE FOR PROTEINS

By Dr. F. H. C. CRICK, F.R.S., LESLIE BARNETT, Dr. S. BRENNER
and Dr. R. J. WATTS-TOBIN

Medical Research Council Unit for Molecular Biology,
Cavendish Laboratory, Cambridge

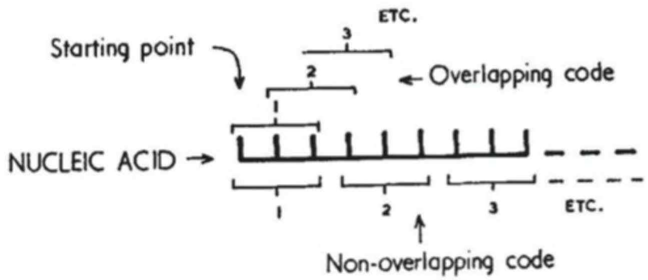


Fig. 1. To show the difference between an overlapping code and a non-overlapping code. The short vertical lines represent the bases of the nucleic acid. The case illustrated is for a triplet code

Vol. 53, 1965 *BIOCHEMISTRY: NIRENBERG ET AL.* 1161

[12] Setlow, R. B., and J. K. Setlow, these Proceedings, **48**, 1250 (1962).
[13] Setlow, R. B., and W. L. Carrier, these Proceedings, **51**, 226 (1964).
[14] Pettijohn, D., and P. Hanawalt, *J. Mol. Biol.*, **9**, 395 (1964).

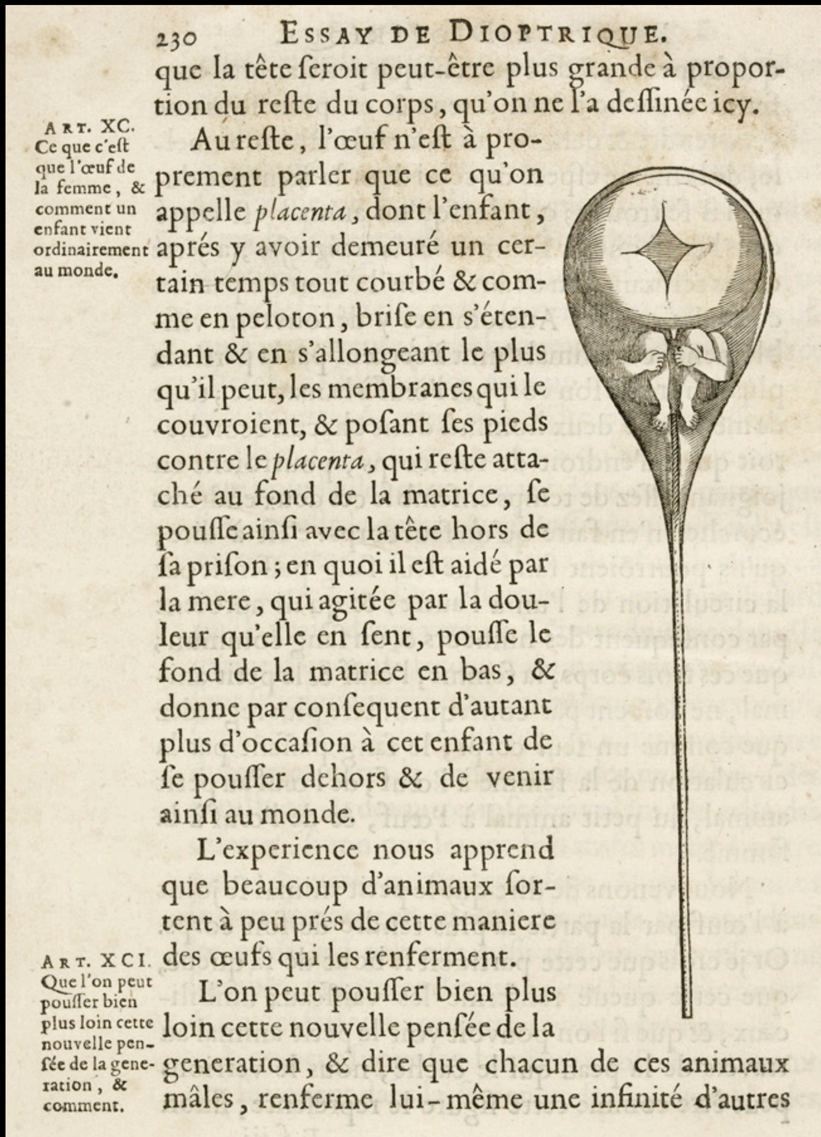
RNA CODEWORDS AND PROTEIN SYNTHESIS, VII. ON THE GENERAL NATURE OF THE RNA CODE

By M. Nirenberg, P. Leder, M. Bernfield, R. Brimacombe, J. Trupin,* F. Rottman†, and C. O'Neal

NATIONAL HEART INSTITUTE, NATIONAL INSTITUTES OF HEALTH, BETHESDA, MARYLAND

Communicated by Robert J. Huebner, March 26, 1965

Examples of idea of "preformation"



230 ESSAY DE DIOPTRIQUE.

que la tête ſeroit peut-être plus grande à proportion du reſte du corps, qu'on ne l'a deſſinée icy.

ART. XC. Ce que c'eſt que l'œuf de la femme, & comment un enfant vient ordinairement au monde.

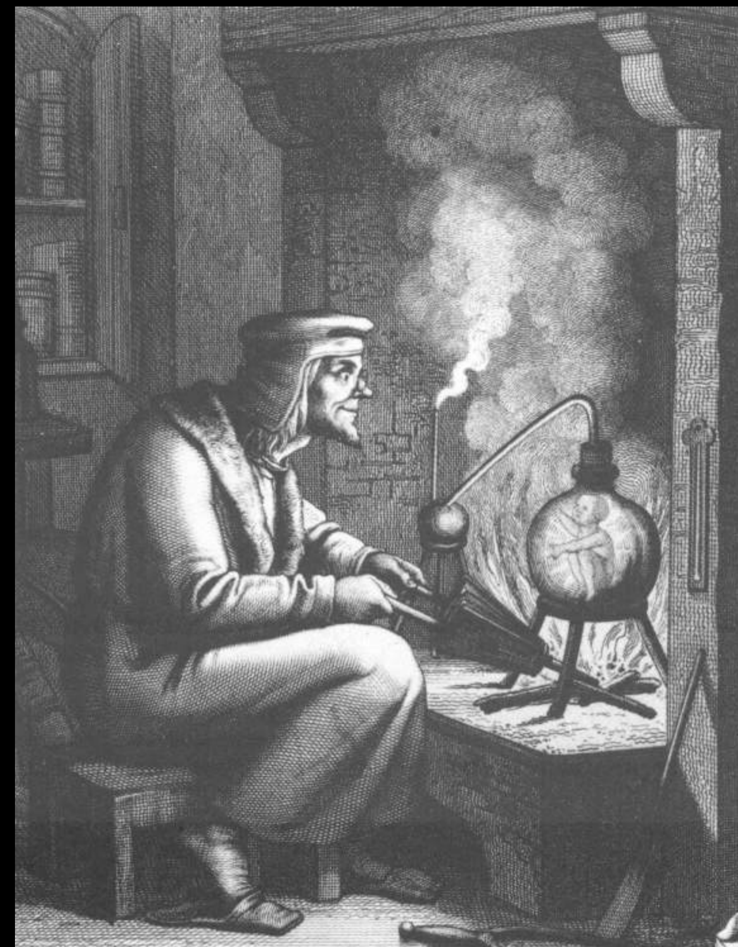
Au reſte, l'œuf n'eſt à proprement parler que ce qu'on appelle *placenta*, dont l'enfant, aprés y avoir demeuré un certain temps tout courbé & comme en peloton, briſe en s'étendant & en s'allongeant le plus qu'il peut, les membranes qui le couvroient, & poſant ſes pieds contre le *placenta*, qui reſte attaché au fond de la matrice, ſe pouſſe ainſi avec la tête hors de ſa priſon; en quoi il eſt aidé par la mere, qui agitée par la douleur qu'elle en ſent, pouſſe le fond de la matrice en bas, & donne par conſequent d'autant plus d'occaſion à cet enfant de ſe pouſſer dehors & de venir ainſi au monde.

L'experience nous apprend que beaucoup d'animaux ſortent à peu prés de cette maniere des œufs qui les renferment.

ART. XCI. Que l'on peut pouſſer bien plus loin cette nouvelle penſée de la generation, & comment.

L'on peut pouſſer bien plus loin cette nouvelle penſée de la generation, & dire que chacun de ces animaux mâles, renferme lui-même une infinité d'autres

Hartsoeker, Nicolaas. 1694. *Essay de dioptrique*. Paris: Jean Anisson, 230.



19th-century engraving of Wagner and Homunculus from Goethe's *Faust II*

ARISTOTLE

GENERATION OF ANIMALS

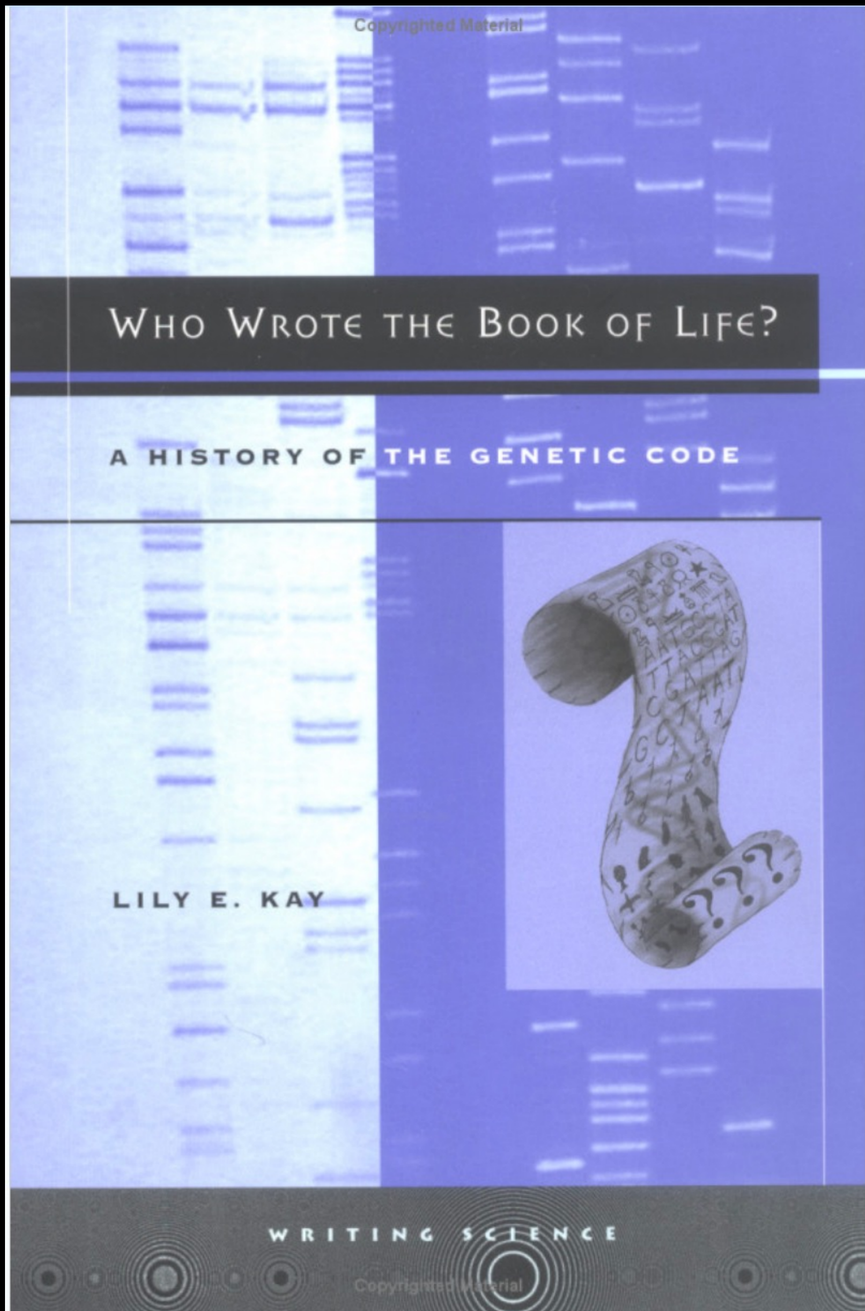
WITH AN ENGLISH TRANSLATION BY

A. L. PECK

HARVARD UNIVERSITY PRESS
CAMBRIDGE, MASSACHUSETTS
LONDON, ENGLAND

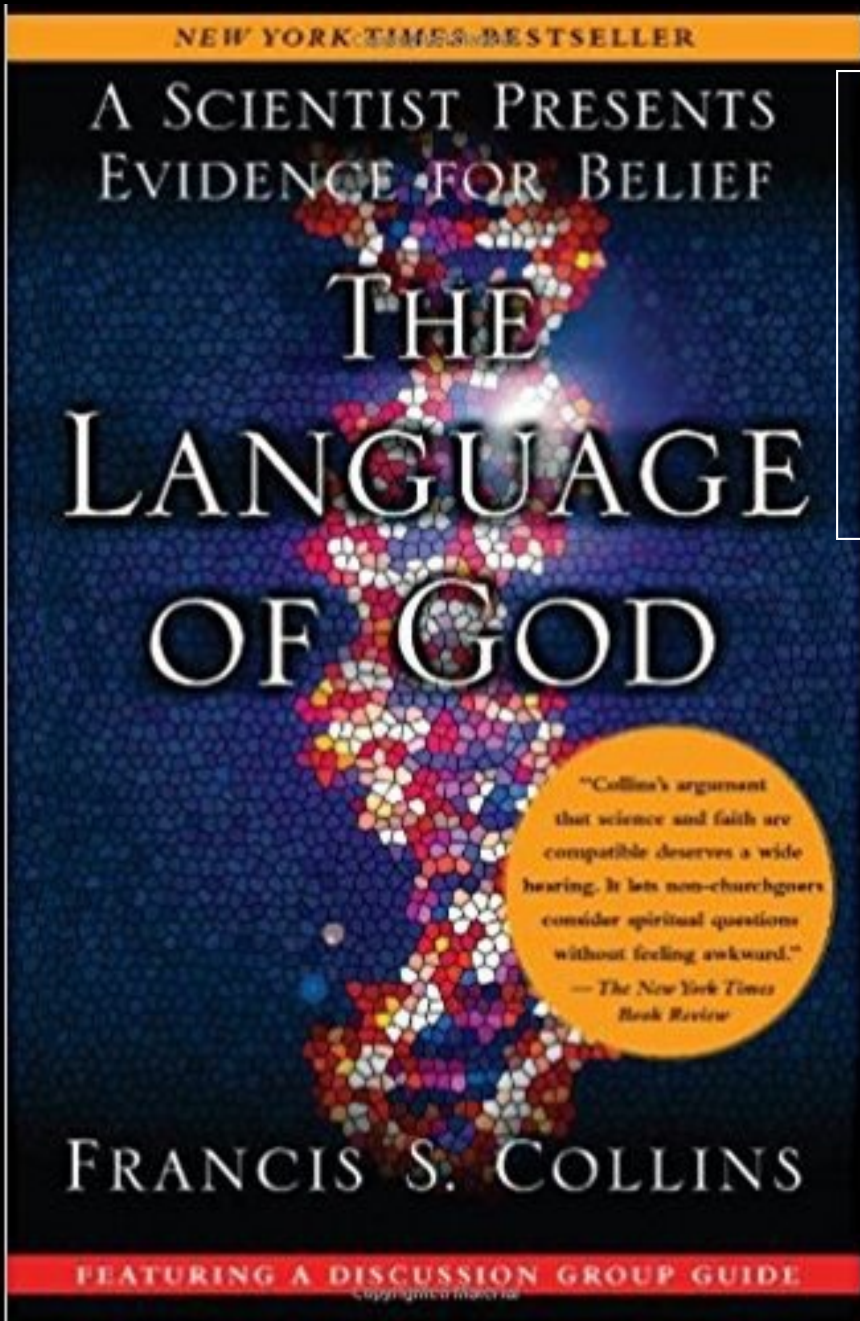
Aristotle (384-322 BCE)

"The male provides the 'form' and the 'principle of movement', the female provides the body, in other words, the material" (I.XX.729a).

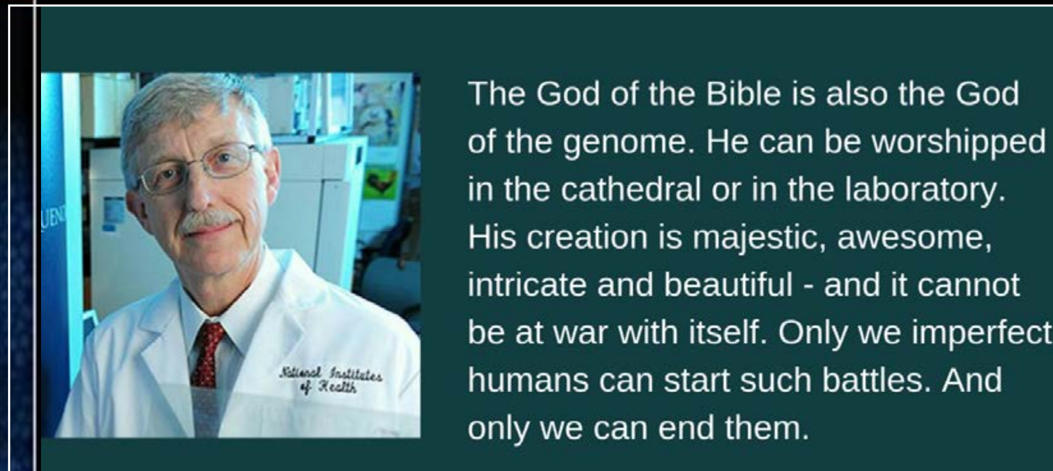


Kay, Lily E. *Who Wrote the Book of Life?: A History of the Genetic Code.* Stanford University Press, 2000.

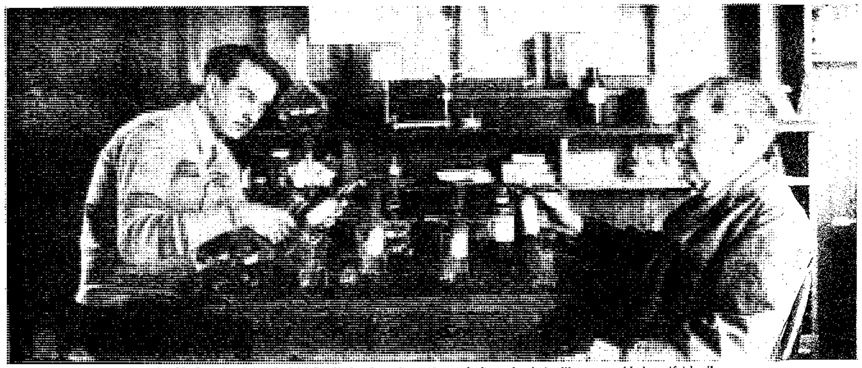
Lily Kay
(1947-2000)



Collins, Francis S. *The Language of God: A Scientist Presents Evidence for Belief*. Free Press, 2007.



Francis Collins, Director of National Institutes of Health, Bethesda, Maryland, United States.



Dr. MacDougal and (on the left) Dr. Clarke, the author, trying to duplicate the elusive life process with the artificial cell

What Is Life?

The Puzzling Phenomenon Called "Life" Is Being Studied by Means of a Working Model of a Living Plant Cell

By Beverly L. Clarke

WE are so far from a perfect understanding of life that even active workers in biological research cannot agree as to the real nature of life—whether it is purely a matter of chemistry and physics and evolution and chance, or whether there will indeed prove to be an element of the nature of the "spark of life" of the ancients, transcending mortal understanding.

Of great interest in this connectiou are some recent experiments by a distinguished American physiologist, Dr. D. T. MacDougal, Director of the Carnegie Institntion of Washington's Laboratories for Plant Physiology at Tucson, Arizona, and Carmel, California.

For many years Dr. MacDougal has been studying the phenomenon of life by a very rational method. He has chosen as his materials chemical substances of the same nature as those occurring in living matter, and has subjected them, singly and in combinations, to the various conditions to which living material itself is normally exposed. He has made elaborate studies of the action on these materials of certain physical processes believed to play important roles in life.

Such a process is that known as swelling, wherein certain semi-solid substances like gelatin, wheu immersed in water, will attract to themselves molecules of water which they hold with great force, with consequent increase in size. There is no doubt that swelling is an intimate associate of most life processes. Someone has suggested that the mechanism of muscle action is simply a matter of swelling and shrinkage of the muscle fibres. Dr. MacDougal has invented an instrument (shown on page 83) for making an automatic record of the swelling in liquids of gelatin plates or of sections cut from the living cactus plant.

It is now generally known that the unit of living matter is the cell. The cell is the building-stone—the brick—from which all plants and animals are constructed. Life may indeed be regarded as the resultant action of the cells of which the organism is composed. What more natural, then, than to concentrate attention on the single cell? There is little doubt that these microscopic objects hold the key to the full understanding of life.

Dr. MacDougal has made a deep study of the known facts about cells. He has dealt particnlarly with plant cells, but that does not destroy the general character of his results. Viewed as a piece of architecture—as one wonld view a large building or the ground-plan of a town—the cell is a fairly simple affair. Figure 1 gives a general idea of the plant cell. It develops from a tiny mass of jelly, and the first change is perhaps a matter of self-protection—the outer layer of this ball of jelly undergoes a hardening process which forms it into a tough protecting sheath.

Most Primitive Plants Are Single Cells

As the cell enlarges, first by the addition of more material and then by absorption of water, the central portion becomes a hollow, water-filled cavity and the jelly-like protoplasm is pushed towards the outer wall to form the soft, semi-solid layer we call the plasma, or plasmatic layer. If now we place in the plasmatic layer a number of dark-colored bodies, the picture is complete. The simplest plants and animals—the ancestors of us all—consist of only one cell which under the microscope looks very much like this.

The natural sequel to Dr. MacDougal's series of researches on the chemistry of protoplasm was an attempt to construct a model of the living cell, of similar materials arranged in similar relations to each other as in the actual cell.

Much experimentation was necessary before the present model of the "artificial cell" was designed. Figure 2 shows this model. The framework on which the cell is built is a paper thimble about one inch in diameter and three inches high. This thimble, being pure cellulose, also serves admirably as the external cell-wall.

The first step in the limitation of the plant cell is the deposition within the meshwork of which the cellulose thimble consists, of substances of sugar-like composition and jelly-like consistency. Such substances are agar-agar, which is extracted from a kind of sea-weed and comes in crisp flakes like breakfast food, and pectin, a similar material found abundantly in apples. These substances are dissolved in boiling water to a thick, brownish syrup, into which the thimble is dipped. In order to obtain the desired physical structure, the thimble is now treated with alcohol, which abstracts part of the water. Next is prepared a solution of a mixture of gelatin and agar in proper proportions. To this is added a small quantity of some fat, a little soap, and a minute trace of salt. All these are included to represent actual conditions in plant protoplasm, which contains a very small amonnt of a great many substances. A layer of this hot mixture, a quarter of an inch thick, is applied to the inner snrface of the thimble and allowed to harden, representing the plasmatic layer.

A rubber stopper carrying glass tubes is inserted in the thimble, and a solution of sugar is poured in to represent the cell sap. The "artificial cell" is now ready for operation.

What will it do? In general, it may be answered that this artificial cell will do a great many things that its living model does. If the cell, constructed as described and filled with sugar solution, is placed in a glass beaker containing either pure water or a solution of some salt, water alone or water plus particles of salt will pass through the cell wall and into the solution of sugar. If the cell was originally full of sugar solution, any further liquid passing into it will cause an overflow through the tube B (Figure 2), the amount of which overflow serves as a measnre of the activity of the cell.

In the case of the living cell, much is known about

What *Is* Life?

Fascinating Pseudo-cells Which Display the Non-Living Features of Protoplasm May be Made by the Amateur With a Few Chemicals

By EMMA REH STEVENSON

CHOOSING for his field of research for 30 years the borderland between the inorganic and organic world of matter on the fringe of recognized science, Professor Alfonso L. Herrera, chief of the division of biology of the Mexican Department of Agriculture, has obtained curious evidence that may relate to the origin of life upon earth.

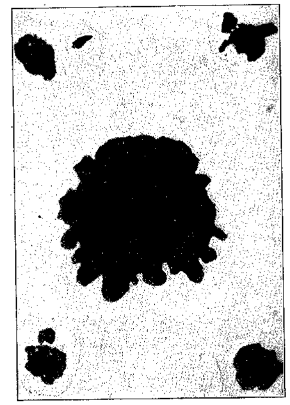
He has taken both mineral and organic substances and created from them pseudo-cells and pseudo-protoplasms that mimic life itself. His microscope has revealed imitation cells that resemble very closely those of living organisms, amoebæ, spores, streptococcus chains, bacteria, and the structure of protoplasm.

PROFESSOR HERRERA makes no extravagant claims. He merely shows that the mysterious activities of life cells and the special forms and shapes of living substance can be imitated by common mineral and organic materials that do not possess the so-called life force. He therefore believes that life is not a special phenomenon, but a property which all matter possesses under the right conditions.

Perhaps the most interesting of all of his "artificial beings," as Professor Herrera calls his imitation cells, are his "colpoids" which resemble both in appearance and in behavior the creatures called amoebæ by scientists.

He treats the visitor to his laboratory to a sight of the antics of his favorite laboratory "children." He dissolves 50 parts of olive oil in 100 parts of gasoline, and 14 parts of soda lye in 100 parts of distilled water, adding a pinch of aniline black to this latter solution so that the observer can distinguish the two.

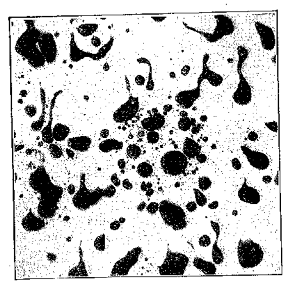
The oil-and-gasoline solution he puts into a porcelain dish with a flat bottom which he levels mechanically so that any movements in the liquid will not be due to gravity. With an eye dropper he takes a small amount of the black soda solution and inserts it under the surface of the gasoline-oil mixture. Then he hands the visitor the magnifying glass.



THE EXPERIMENT

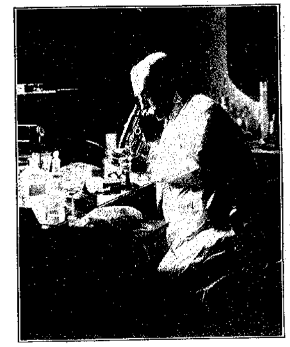
The several ingredients are mixed, and a drop of the soda solution "comes to life"

Almost immediately things begin to happen. The black drop becomes alive and begins to sway and tremble and shake itself. It begins to pant and breathe and divide itself into parts. These parts begin to skip around rapidly in a dissatisfied manner, pursuing, evading, and battling with other droplets for their bodies. They extend armlike appendages and fight vampire fights.



THE SECOND STAGE

One large drop breaks into rapidly moving parts which shake and tremble



PROFESSOR A. L. HERRERA

In his laboratory at the Mexican Department of Agriculture where he experiments

They act for all the world like real single-celled living creatures going through the ordinary routine of life. They "eat" and "reproduce" like the amoeba swimming in a pond looking for its daily bread and peopling it with other amoebæ.

Professor Herrera does not claim that his oil-and-soda creatures are alive, for he can explain their strange life-like antics and amoeba-like shapes by well-known chemical and physical theories. The oil-and-soda solutions react according to the chemical process of saponification, a process the housewife used to take advantage of when she made her own soap, using rendered animal fats and leached lye from wood ashes.

WHEN a drop of the black soda solution is placed in the oil mixture, saponification immediately begins to take place around the outside of the drop, forming a thin membrane of soap around it. Then there is a black solution of one nature wrapped in a delicate bag and suspended within another solution of an entirely different disposition and character.

The soap bag which encloses the soda drop, like the membranes that envelop animal and vegetable cells in real life, is semi-permeable, and permits certain molecules to pass through. A social war of equalization takes place in an effort to make conditions on the inside of the drop more like those on the outside.

The equalization struggle is the process of saponification. Under the microscope this ordinary struggle of one solution on the outside looking in with the other one on the inside looking out, is fascinating to watch.

Tiny currents of excited material seem to be streaming through the pores of the membrane, and an active interchange of material is seen to be taking

Life is a pattern in spacetime, rather than a specific material object.

Self-reproduction, if not in the organism itself, at least in some related organisms.

Information storage of a self-representation, e.g. DNA molecules.

A metabolism which converts matter and energy from the environment.

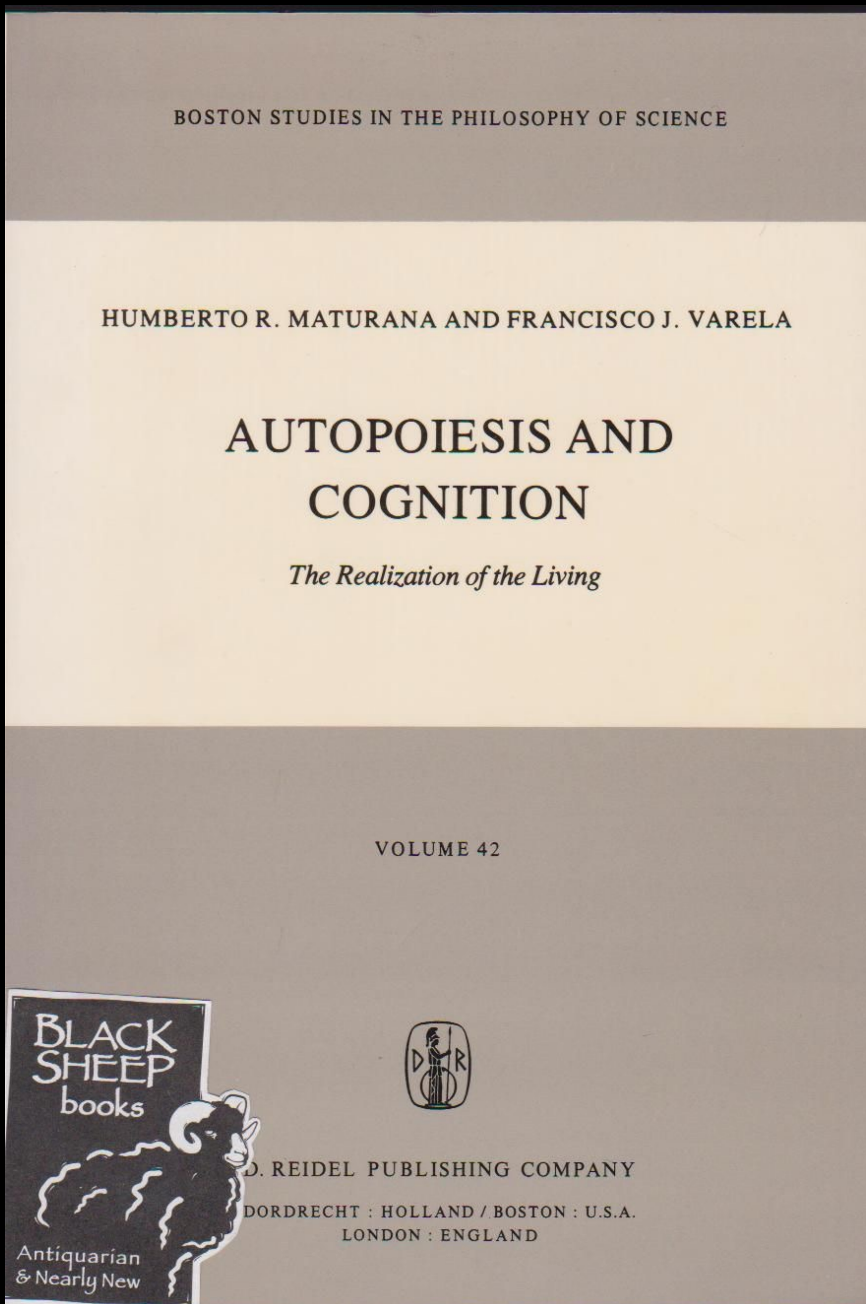
Functional interactions with the environment.

Interdependence of parts.

Stability under perturbations and insensitivity to small changes.

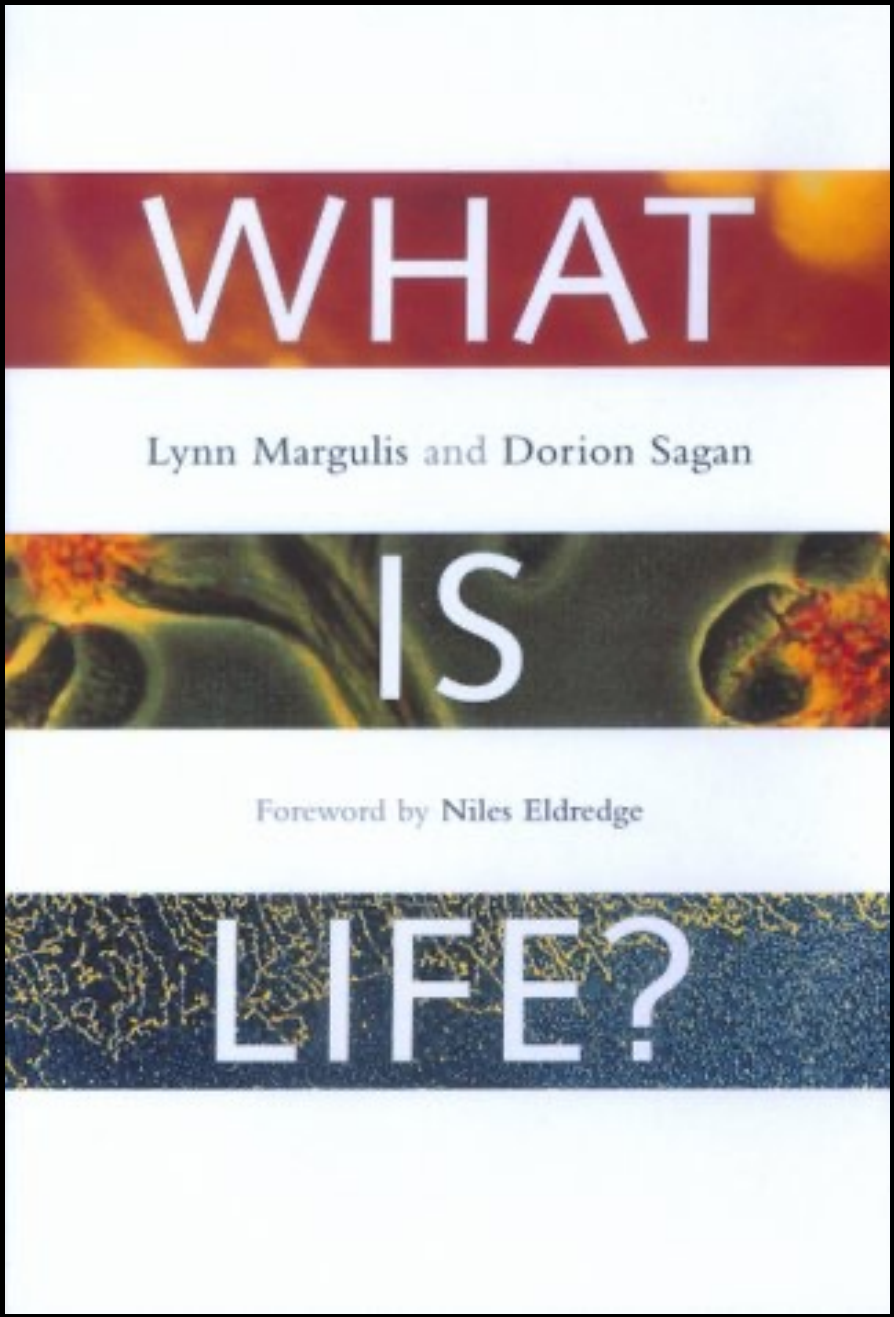
The ability to evolve. Not a property of an individual organism, but of its lineage.

Farmer, J. Doyne, and Alletta d'A. Belin. "Artificial Life: The Coming Evolution." In *Artificial Life II*. Edited by by Christopher G. Langton, Charles Taylor, J. Doyne Farmer, and Steen Rasmussen. Westview Press, 2003.



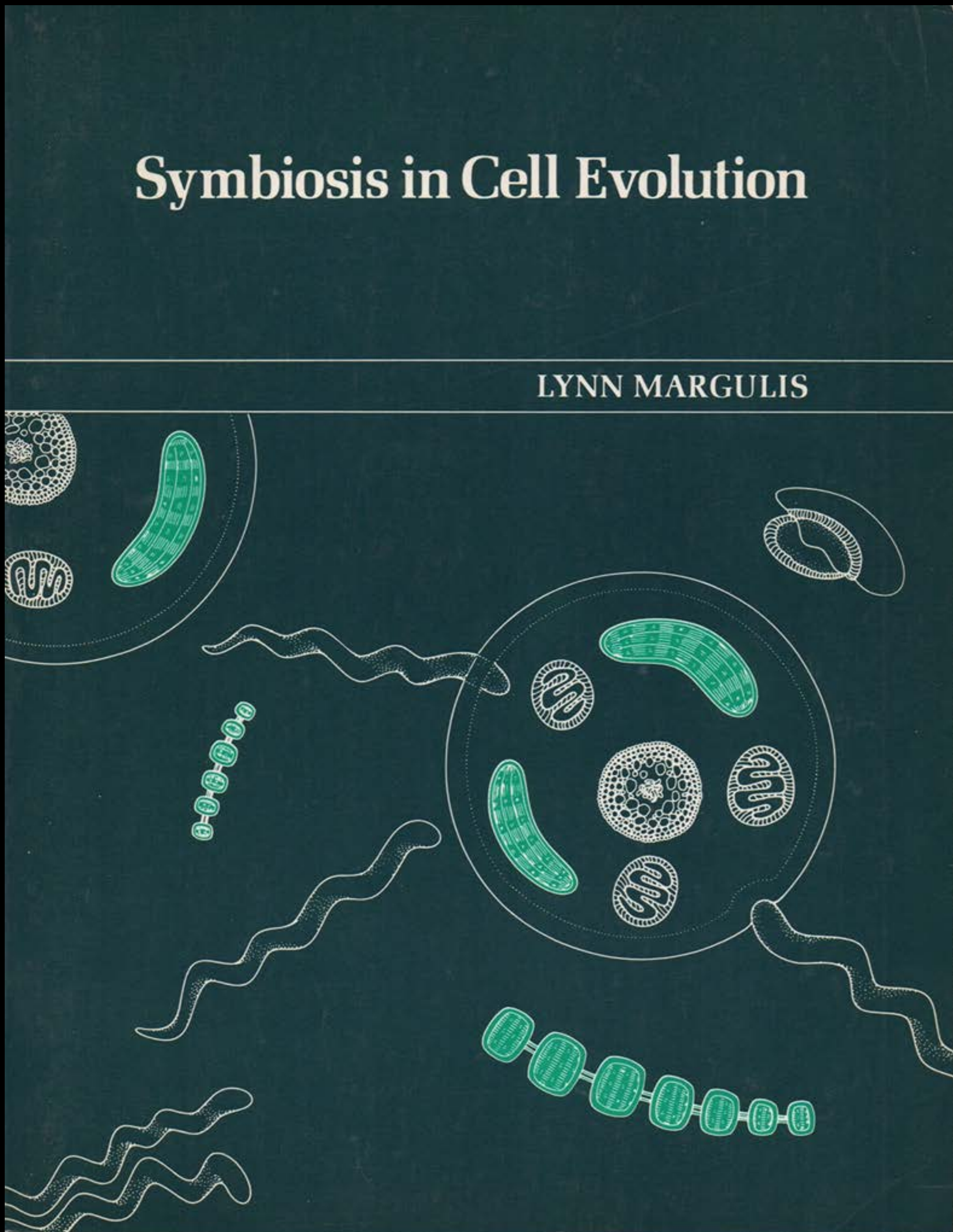
Francisco Varela (1946-2001) and Humberto Maturana (1928-2021)

"An autopoietic [system] … is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them."

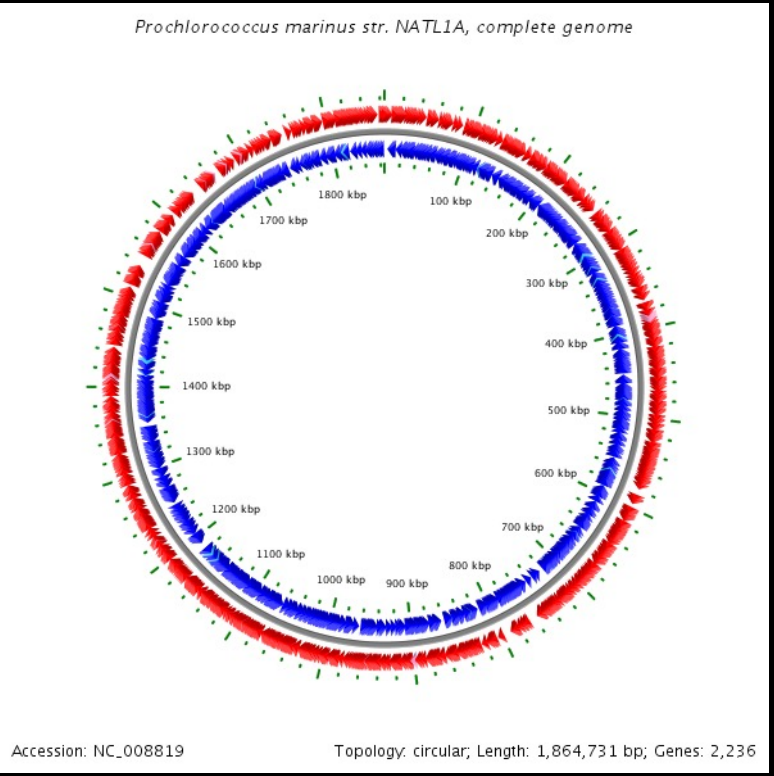


Lynn Margulis
(1938-2011)

"Life — from bacterium to biosphere — maintains by making more of itself." Life "moves and expands incessantly." "Life is edible, lovable, lethal."

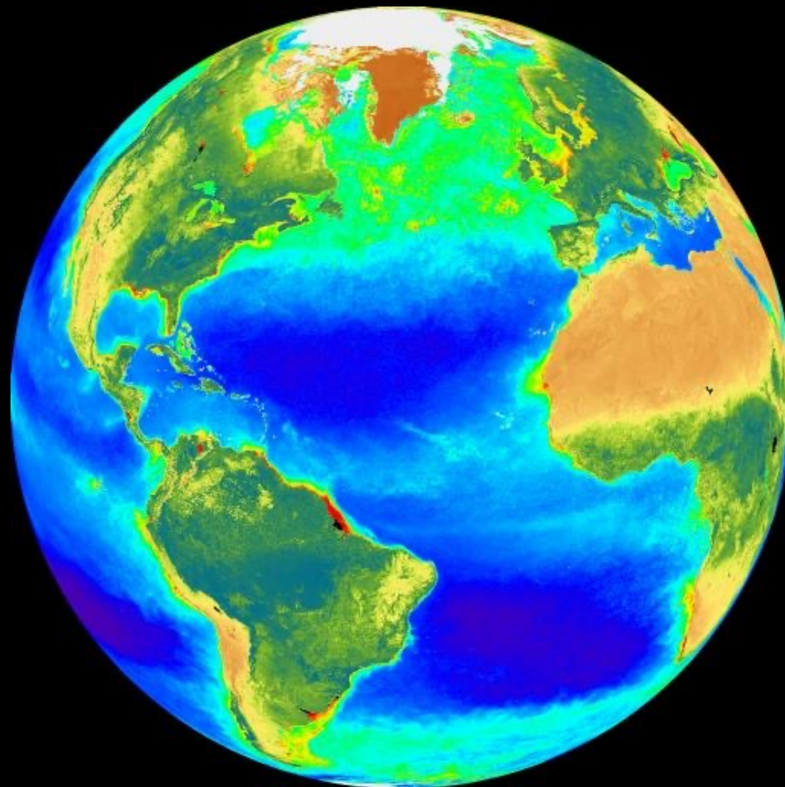


Lynn Margulis
(1938-2011)



"I consider this the minimal life form — having the smallest number of genes that can make life from light and only inorganic compounds. It is the essence of Life."

Penny Chisholm, 2004



"think of life as something with properties similar at all scales, a system of self-stabilizing networks. Life is a hierarchy of living systems."

Penny Chisholm, 2004

SYMPOIETIC AND AUTOPOIETIC SYSTEMS: A NEW DISTINCTION FOR SELF-ORGANIZING SYSTEMS

Beth Dempster
School of Planning, University of Waterloo

ABSTRACT

Heuristics provide essential tools for understanding living systems, their cha[…] and their behaviours. My intent in this paper is to describe a considerabl[…] heuristic than the conventional tools. My motivation is a concern that heuristic[…] the organism metaphor are often inappropriate and misleading for understandin[…] systems. I propose a new concept based on an interpretation of ecosystems: […] systems. These are complex, self-organizing but collectively producing, boundaryless systems. A subsequent distinction between sympoietic and autopoietic systems is discussed. This distinction arises from defining a difference between three key system characteristics: 1) autopoietic systems have self-defined boundaries, sympoietic systems do not; 2) autopoietic systems are self-produced, sympoietic systems are collectively-produced; and, 3) autopoietic systems are organizationally closed, sympoietic systems are organizationally ajar. A range of other characteristics arise from these differences. Autopoietic systems are homeostatic, development oriented, centrally controlled, predictable and efficient. Sympoietic systems are homeorhetic, evolutionary, distributively controlled, unpredictable and adaptive. Recognized as caricatures at ends of a conceptual continuum, these descriptions present a useful heuristic. By introducing an alternative to the organism metaphor, the conceptualization of sympoietic systems draws attention to many, often neglected, complex system characteristics. In addition, the heuristic provides a means for recognizing trade-offs between the two sets of characteristics that are associated with the two system types. These, and other distinctions, lead to a range of new questions that have significant implications relevant to understanding complex living systems. Since it is based on generic system descriptions, the heuristic can be applied to a wide range of situations, including social, political, economic and cultural systems.

Keywords: autopoiesis, sympoiesis, self-organizing systems, boundaries

AUTOPOIETIC SYSTEMS	SYMPOIETIC SYSTEMS
tree	forest
individual human	community
clique or group-think	open group
technical jargon	common english
expert driven task force	participatory process
normal science	post-normal science

Table 2 – Examples of autopoietic and sympoietic systems

paper presented at Proceedings of the World Congress of the System Sciences and ISSS, 2000, Toronto, Canada.

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Gaia Theory: Between Autopoiesis and Sympoiesis

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Abstract. The article discusses the development of the Gaia Hypothesis as it was defined by James Lovelock in the 1970s and later elaborated in his collaboration with biologist Lynn Margulis. Margulis's research in symbiogenesis and her interest in Maturana and Varela's theory of autopoiesis helped to reshape the Gaia theory from a first-order systems theory to second-order systems theory. In contrast to the first-order systems theory, which is concerned with the processes of homeostasis, second-order systems incorporate emergence, complexity and contingency. In this respect Latour's and Stengers's takes on Gaia, even defining it as an "outlaw" or an anti-system, can be interpreted as specific kind of systems thinking. The article also discusses Haraway's interpretation of Gaia in terms of sympoiesis and argues that it presents a major reconceptualization of systems theory.

Keywords: Gaia, systems theory, Lovelock, Margulis, autopoiesis, sympoiesis


Disarming the immune system's "atomic bomb" cells p. 1067
The origins of peanut allergy p. 1072
A central psychosomatic stress pathway p. 1105
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Watching liquid crystal defect dynamics pp. 1075 & 1120

"Astrobiology is an interesting mixture of scientific processes. One emerges from the historical sciences that make up a large part of the astrobiology enterprise: astronomy, ecology, field biology, geology, oceanography, paleontology, and others. The events being investigated have happened, and it is the task of the scientists to tell the explanatory story. It is inductive science in that the data are collected first and then the hypothesis is formulated. . . . A second scientific approach emerges from the ethos of contemporary medical/biological research. It is deductive in the sense that it is hypothesis driven. There is a strong emphasis on experimentation, in which the scientist creates his or her own universe that is, or is assumed to be, a simulacrum of the real world beyond the laboratory bench … life has the characteristic, using philosophical terminology, of 'being' and 'becoming.' It exists in a particular form now, but has the potential, because of the diversity in its offspring, of becoming something related, but also different."

Blumberg, Baruch S. "The NASA Astrobiology Institute: Early History and Organization." *Astrobiology* 2, no. 3 (2003): 463–70.

BOSAK LAB
Geobiology at MIT

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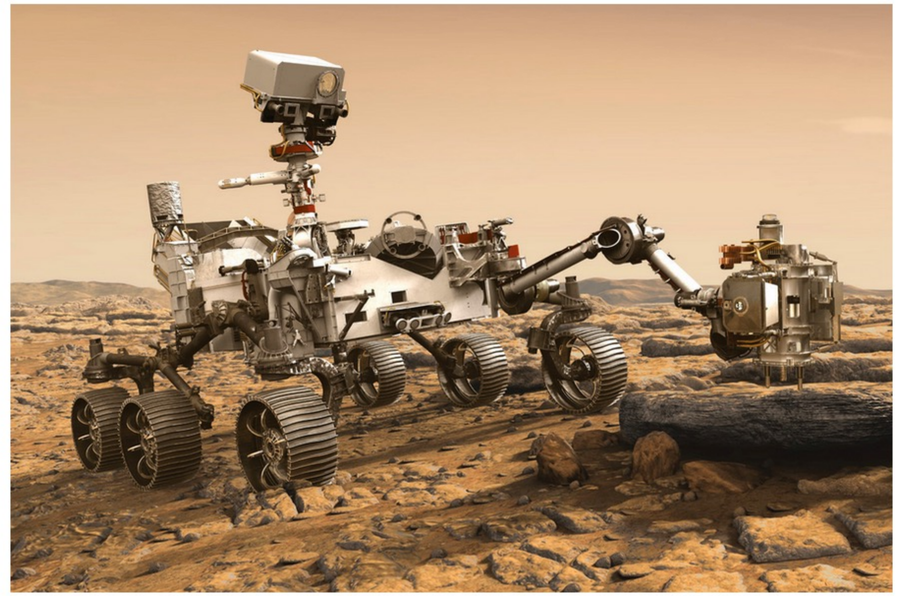
Welcome to the Bosak Lab!

The Bosak laboratory uses experimental geobiology to explore modern biogeochemical and sedimentological processes in micro systems and interpret the record of life on the Early Earth.

With Perseverance, MIT teams prepare for Mars rover landing

Following touchdown, MOXIE will brew up oxygen while geologists comb for sediments to sample.

Jennifer Chu | MIT News Office
February 17, 2021



On Thursday, NASA's newest Mars rover, Perseverance, is scheduled to touch down on the surface of the Red Planet following a nail-biting entry and descent sequence vividly known as the "seven minutes of terror." If all goes according to plan, the car-sized explorer will blast safely down into Jezero Crater, a 28-mile-wide impact basin that once may have hosted a river delta flooded with water, and possibly life.

Over the next year and a half of its primary mission, Perseverance will explore the crater and collect rock samples that will one day be returned to Earth, where scientists hope to study them for evidence of ancient microbial life.

As the rover traverses the empty lake bed, it will determine which sediments to sample, with the help of MIT's Tanja Bosak, professor of geobiology, and Benjamin Weiss, professor of planetary sciences. Bosak and Weiss are members of the mission's return sample science team and will be using the rover's images to direct the vehicle toward interesting sediments to collect.

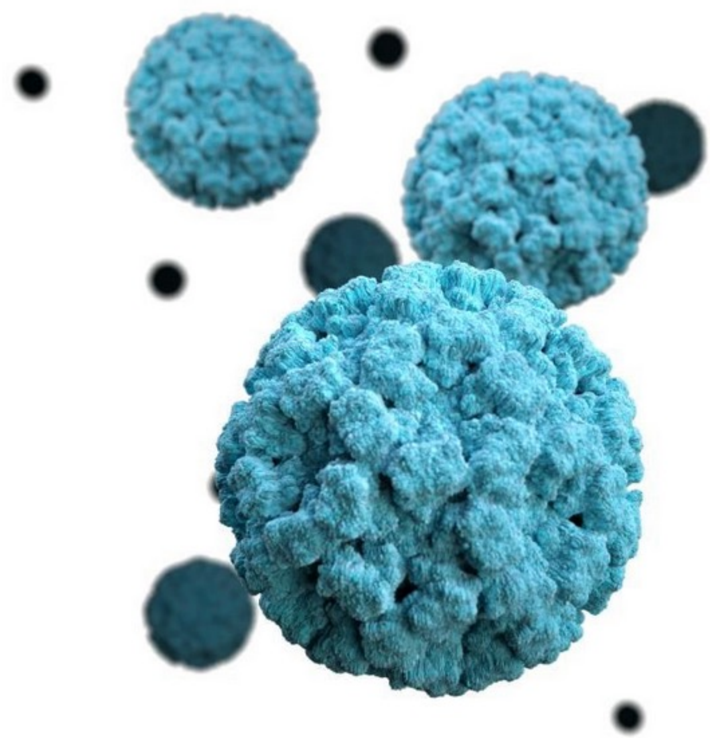
Chu, Jennifer. "With Perseverance, MIT Teams Prepare for Mars Rover Landing." February 17, 2021. MIT News.

What is Life? A Crash Course to Autopoiesis

From viruses to cognition, **Natalia Zdorovtsova** explains how defining life as systems of interactions can give new insight into its nature

by **Natalia Zdorovtsova**

Friday January 22 2021, 12:00pm



What exactly constitutes life? In the case of viruses (such as the norovirus shown above), biologists have tended to make up their minds based on the fact that viral replication depends on a host organism
ALISSA ECKERT/CENTERS FOR DISEASE CONTROL AND PREVENTION

This past year, we've heard a great deal of rhetoric that attempts to anthropomorphise SARS-CoV-2, the viral antecedent of COVID-19. This is best exemplified by PM Boris Johnson's insistence that the virus is an "invisible enemy" to be defeated and a "common foe" to all of humanity. This comes with a clear political intention — to resurrect a certain wartime mentality within the British public — but also raises an interesting question relating to the nature of viruses. To what extent can they be personified? And, indeed, are they *living*?