The True Secret of Evolution

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From Competition to Collaboration

By

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and Lourdes Velázquez

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PREFACE

Evolutionism is little more than two centuries old, and yet it has a history so rich in discoveries and debates that it is almost unparalleled in the history of science. Likewise, to a notable extent, it has had an impact on the way in which humans have considered and consider themselves. This breadth of repercussions and meanings seems surprising at first sight, if one considers that it only affects one scientific discipline: biology. However, it is easy to realize that biology directly concerns our constitution, as human beings, since ancient times, have been classified as animals, although specifically characterized with the condition of rationality, as it was already evident from Aristotle's classical definition. It is no way comparable, therefore, with the advent of the Copernican theory which, by getting rid of the hundreds-year-old Ptolemaic theory, in the mid-16th century upset the entire support of cosmology on which complex philosophical and theological doctrines laid. However, it is not difficult to see that the history of evolutionism does not constitute an abundance of new data and new discoveries, but the appearance and confrontation of novel ideas that suggested unprecedented interpretations of facts known for centuries. From here theories arose that stimulated naturalists to search for new facts that would allow them to corroborate their respective theories and overcome their insufficiencies.

Precisely because it also refers directly to the nature of humans, evolutionism inevitably met those articulations of knowledge and human convictions that since immemorial time have been the object of philosophy, religions, and many other expressions of human culture. On the other hand, it must be recognized that within evolutionism a series of positions that we would qualify as ideological have also been established, in the sense that they assume Darwin's theory as the only scientifically proven and accepted one, centered on natural selection as an explanatory mechanism of the transformation of the species, and presenting the variety of theoretical positions present in evolutionary studies today as a normal phenomenon of discussion or controversy that takes place in every field of scientific

research. In reality, this is not the case: neo-Darwinism is the expression of a materialist metaphysical conception that sees in natural selection simply the process by which certain individuals - belonging to a certain species and randomly endowed with a characteristic that allows them to survive when resources are scarce in that given environment -transmit their characteristics on to their descendants; this results in the total occupation of the environment in the long term, since the other individuals not so endowed become progressively extinct.

The considerable propaganda weight of the neo-Darwinians had led to the dismissal of Lamarck, who had anticipated Darwin's *on the Origin of Species* by 50 years, by attributing to living beings the internal drive to actively adapt to the environment, developing organs and functions that then passed on to their descendants. The acceptance of Lamarckism was blocked at the end of the 19th century by Weissmann's doctrine on the total separation of the somatic plasm, which constitutes the body of the living cell, from the germinal plasm, contained in the gametes, which are present in the genital organs and are the only ones that regulate reproduction. Thus, the somatic characteristics that an individual can accumulate are not heritable. Therefore, many neo-Darwinians accuse those who do not accept their theories of denying evolution.

This is a false accusation, the refutation of which requires adequate clarification. We must first point out what the evolutionary thesis consists of: it affirms that current species derive by descent from less numerous and less complex original species. Nonetheless, we must realize that this statement constitutes a theory, which does not consist of the mere exposition of empirical data. On the other hand, it can be said that this theory - which we will call evolutionary theory - can now be considered scientifically corroborated, although several professional biologists deny it. At this point, the problem of understanding and explaining how the evolution arises, and here various theories of evolution come into play, each of which has its strengths and weaknesses. The strengths basically consist of recognizing that contact with the environment does affect the organism of living beings and produces changes that are transmitted to offspring.

The book that we present here illustrates precisely some phenomena that support this possibility (in the first part by the biologist Carlo Bellieni), but that do not imply only natural selection. Basically, these are cases where what we could call a certain mixture between parts of living organisms belonging to different species, is produced by contact at the environmental level and gives rise to a new species, without the need for the intervention of the germinal plasma (but There are even cases where the action of the environment can cause changes in expression of the individual's DNA). It is a kind of "horizontal" genetic exchanges between living individuals, in which concepts such as horizontal gene transfer and epigenesis play an essential role, which the author illustrates in a balanced way, generally limiting himself to stating the question of whether this collaborative vision of the different species to better adapt to the environment is not more satisfactory from the scientific point of view than the neo-Darwinian vertical perspective that is limited to admit chance and the determinism of physical laws.

This volume is a work of high dissemination, that is, it is clear, orderly and easy to read, in which the second part, due to Lourdes Velázquez, highlights the various concepts and principles that have entered into the genesis and developments of the evolutionary theory and theories of evolution. Thus, it is easy to understand that the progress of scientific knowledge tends to offer more problems than solutions, more questions than answers, but that is precisely the characteristic of human progress, which feeds on the investigative spirit instead of adapt to the comfort of the practical results that scientific and technological progress has provided us.

If we stopped here, we would ignore the most original and stimulating aspect of this work, which, under its calm and modest tone, actually proposes an inversion of the Darwinian perspective and its applications in the social field. The image of nature and society is no longer presented as a fierce competitive struggle without exclusion of means, in which the strongest individuals prevail because they are by chance the most apt and lucky to prevail in a certain environment (social Darwinism). Instead, it illustrates a picture in which living beings naturally tend to create conditions of symbiosis, exchange, and collaborative coexistence from which even evolutionary progress flows. Hence, the message about the coexistence of

human beings, in which tolerance, collaboration and solidarity can promote progress for all. This is the true secret of evolution to which the title of this volume refers, and which is presented as a message of wisdom.

Evandro Agazzi

INTRODUCTION

This book aims to present the new acquisitions in the evolutionary field; but it has also another aim: to show the way, the path through which they have asserted themselves and evolved. Yes, because science is like this: only amateurs could think that the scientist is the pompous character sure of himself, who believes he knows and gets confused with his role by giving himself extreme importance and mocking others. Unfortunately, this is what emerges from school books. The true scientist is humble because he knows the difficulties he has gone through to get where he is and knows the limits of what he has discovered. In fact, a sure way to understand if we are faced with a scientific work or a boast is the use of verbs: the boaster, speaking of himself or of a scientist he approves of, uses the verb "discover"; the scientist never uses it: if anything, he uses the verb "find". And the boastful scientist identifies with his role. Jaques Lacan said that "The madman is he who believes he is Napoleon; but there is an even madder madman: he is a king who believes he is a king!": It is an aphorism that clearly explains how pomposity and presumption are not the heritage of the true scientist, who has humility in his soul. Bernard of Clairvaux said that "there are those who want to know for the sake of knowing, and this is pure curiosity; there are those who want to know for money and this is greed; there are those who want to know how to build and this is charity; and there are those who want to know to be built, and this is wisdom". Charles Darwin seems to belong to this last group, for two reasons: the first is that he never seemed arrogant and conceited despite his great enterprises; the second is that he always recognized the history from which his greatness and his science came, starting with that of Jacques Lamarck, today banned in schools and widely derided. Lamarck affirmed the evolution of life, placing as the main engine the influence of the environment on the being in mutation. Obviously, neither he nor Darwin had any idea of what DNA was and had little ideas on the modalities of inheritance that had just been advanced by Gregor Mendel.

Let's start this book *ex abrupto* by quoting Darwin who quotes Lamarck. To show how the true scientist knows how to recognize himself as the heir of those who preceded him, in honesty and in rectitude. Charles Darwin so writes in his seminal work "On the Origin of Species by Natural Choice, or the Conservation of Perfected Races in the Struggle for Existence"[1]:

> *Lamarck was the first man whose conclusions on this subject excited much attention. This justly-celebrated naturalist first published his views in 1801, and he much enlarged them in 1809 in his 'Philosophie Zoologique,' and subsequently, in 1815, in his Introduction to his 'Histoire Naturelle des Animaux sans Vertèbres.' In these works he upholds the doctrine that all species, including man, are descended from other species. He first did the eminent service of arousing attention to the probability of all change in the organic as well as in the inorganic world being the result of law, and not of miraculous interposition. Lamarck seems to have been chiefly led to his conclusion on the gradual change of species, by the difficulty of distinguishing species and varieties, by the almost perfect gradation of forms in certain organic groups, and by the analogy of domestic productions. With respect to the means of modification, he attributed something to the direct action of the physical conditions of life, something to the crossing of already existing forms, and much to use and disuse, that is, to the effects of habit. To this latter agency he seems to attribute all the beautiful adaptations in nature; —such as the long neck of the giraffe for browsing on the branches of trees. But he likewise believed in a law of progressive development; and as all the forms of life thus tended to progress, in order to account for the existence at the present day of very simple productions, he maintained that such forms were now spontaneously generated. Geoffroy Saint Hilaire, as is stated in his 'Life,' written by his son, suspected, as early as 1795, that what we call species are various degenerations of the same type. It was not until 1828 that he published his conviction that the same forms have not been perpetuated since the origin of all things. Geoffroy seems to have relied chiefly on the conditions of life, or the "monde ambiant," as the cause of change. He was cautious in drawing conclusions, and did not believe that existing species are now undergoing modification; and, as his son adds, "C'est donc un problème à*

[1] Charles Darwin The Origin of Species. Preface to the Third Edition Available at: http://www.talkorigins.org/faqs/origin/preface.html

réserver entièrement à l'avenir, supposé même que l'avenir doive avoir prise sur lui."

Let us also add another aspect about Darwin's way of conceiving nature and research: wonder. The biological world he studies is not his personal property or his own material to exploit, but is pure wonder. Today the work of a researcher has become very miserable: we research that small area in which we have the funds, avoiding the risk of finding interesting things that could help us understand more about nature, but lead us astray and therefore cause us to lose the funding. For Darwin, what counted was the wonder towards nature and towards himself that he did not consider as the genius who created a new way of conceiving the world (as his followers would have tried to transform him) but as a servant of beauty.

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. 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 by the Creator into a few forms or into one; and that, whilst this planet has gone circling 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."

Epigenetics

In this book we will talk a lot about epigenetics. What is it? It is the ability of the environment to influence genes, something that until few years ago was thought impossible. Today, we know that this is the basis of many phenomena: from the development of metabolic diseases to tumors. The

environment does not alter DNA, but simply changes the way some small pieces called genes express themselves. These alterations are hereditary. But they are certainly not mutations: they are, I repeat, alterations of a function.

So, one might think that the environment does not induce mutations. This is only partly true. Because recently it has been discovered that environmental influences (epigenetics) can change the tendency of some genes to mutate, that is, they make genes almost insensitive to mutations, they protect them. The environment protects the genes. But if the environment protects genes (maybe those which are more useful to the environment itself?) then the causality of mutations is seriously questioned. We will see this in the text.

> "the researchers investigated whether there were links between mutation rates and gene functions. It was found that patches of the genome with low mutation rates were enriched for essential genes with conserved biological functions. Contrastingly, genes which had environmentally conditional functions had very high mutation rates. These results suggested to the researchers that these essential areas of the genome were being protected from mutation due to their importance.
>
> "These are the really important regions of the genome," said lead author Grey Monroe. "The areas that are the most biologically important are the ones being protected from mutation."
>
> When the researchers looked at the thale cress genome in more detail, they found that essential genes had a greater number of epigenomic features associated with low mutation rate. Such features are able to recruit DNA repair factors, thereby reducing the frequency of mutations.
>
> This finding reveals a potential method for predicting whether a gene is likely to mutate or not. It also suggests that the plant has evolved to protect its essential genes from mutation. Therefore, the mutations occurring in the plant are not random at all. [2]

[2] Ormiston S: Genetic mutations can not be random. Front Line Genomics. Available at: https://frontlinegenomics.com/genetic-mutations-may-not-be-random/

Hints to Understand the Importance of Epigenetics

But in this introduction, we will point out how the development of science, following the example of Darwin, breaks down barriers, prejudices, and dogmas. This is the case of the so-called Weismann criterion, according to which the environment does not influence DNA. For decades this has been a real dogma of biology, but today this dogma, as happens with all fundamentalisms, has collapsed. And it has opened the way, as we will see in the book, to an interpretation of evolution based on the interaction/collaboration between cells, and or between organisms and eventually between species. We will see it again throughout the text, but it is important to underline these words, which are words that go beyond scientific or sectarian ideologies, and open to the thesis of our book: the importance of collaboration in evolution. Consider that until now evolution was seen by certain neo-Darwinians as a struggle for survival, and that, at the human level, this also meant justifying the struggle of peoples to prevail over sources of sustenance, as if nature imposed the seal on a people to prevail, due to its intrinsic characteristics, over other peoples. Eric Nilsson and his colleagues explain the importance of epigenetic inheritance, that is, how the environment can impact evolution. The Weissman barrier (according to which germ cells are the only ones that transmit information to offspring) remains important, but has required qualification in the light of modern understanding of horizontal gene transfer and other genetic and histological developments.

> *"For the past 120 years, the Weismann barrier and associated germ plasm theory of heredity have been a doctrine that has impacted evolutionary biology and our concepts of inheritance through the germline. Although August Weismann in his 1872 book was correct that the sperm and egg were the only cells to transmit molecular information to the subsequent generation, the concept that somatic cells do not impact the germline (i.e., the Weismann barrier) is incorrect. However, the doctrine or dogma of the Weismann barrier still influences many scientific fields and topics. The discovery of epigenetics, and more recently environmentally induced epigenetic transgenerational inheritance of phenotypic variation and pathology, have had significant impacts on evolution theory and medicine today. Environmental epigenetics and the concept of epigenetic*

transgenerational inheritance refute aspects of the Weismann barrier and require a re-evaluation of both inheritance theory and evolution theory"[3].

Gene Horizontal Transfer

A further step that helps to understand how Darwinian theories are more complex today will be illustrated in the book when we will talk about horizontal gene transfer. This term simply means that some organisms can transfer pieces of their DNA to other organisms, and consequently make them produce proteins that can save their lives. This clashes with the fact that mutations are random. A gene that suddenly changes would be causal; but a gene that inserts itself into another organism is not a random mutation, but an unexpected help. Emma Yasinski's article adds evidence on the phenomenon of horizontal gene transfer. Pamela Sotis (in Pennisi's paper) highlights the importance of gene transfer between bacteria to give other bacteria the ability to survive antibiotics.

In the first known example of horizontal gene transfer between a plant and an animal, a common pest known as the whitefly (Bemisia tabaci) acquired a gene from the one of the various plants it feeds on, researchers reported today (March 25) in Cell. The gene, BtPMaT1, protects the insects from phenolic glycosides, toxins that many plants produce to defend themselves against such pests, thus allowing the whiteflies to feast. "This study is seriously cool," says Charles Davis, an evolutionary biologist at Harvard University who was not involved in the study. It "demonstrates yet another nice example of how horizontal gene transfer among eukaryotes confers evolutionary novelty."."[4]

That horizontal gene transfer may have contributed to the colonization of land is pretty exciting," says Pamela Soltis, a plant evolutionary biologist at the University of Florida in Gainesville. (...) Because claims of horizontal gene transfers between bacteria and more complex organisms are often

[3] Eric E. Nilsson, Millissia Ben Maamar y Michael K. Skinner, "Environmentally Induced Epigenetic Transgenerational Inheritance and the Weismann Barrier: The Dawn of Neo-Lamarckian Theory", J Dev Biol, 8(4):28, 4 Dec 2020. doi: 10.3390/jdb8040028

[4] Emma Yasinski, "First Report of Horizontal Gene Transfer Between Plant and Animal", The Scientis, 25 de marzo de 2021. https://www.the-scientist.com/news-opinion/first-report-of-horizontal-gene-transfer-between-plant-and-animal-68597

disputed as contamination, the researchers say they made sure that the sequenced algae were pure and checked that the genes next to the transferred genes were plant like and not bacteria like, as they would be if they were contaminants[5].

This set of data is the introduction to what you will find in the book. Together with important considerations on the social consequences of the limited and discriminatory way of considering evolution on earth. If it is true that evolution has two wings, one of competition and one of solidarity, humans have preferred for the last two centuries to emphasize competition to affirm that some peoples must bear the burden of others' civilization, for being "more fit". A poem by R Kipling, dealing with the white man's burden, is a clear example of this.[6]

This criterion has led to phenomena of racism that had never been seen in the history of the world, marked over the millennia by horrendous oppression of peoples and by horrendous phenomena of slavery, but never scientifically justificating discrimination and abuse.

On the other hand, considering the world as a continuous evolution is a great help and stimulus for curiosity, for the world is a place of continuous change where, especially for science, one can draw the lesson that there is always a further horizon. The idea that the world is not animated by determinism or finalism or even creationism, but by a sort of creative impulse, puts us all in a whirlwind of life that on the one hand can create worry and uncertainty, but within which we always perceive a brilliant order; as in recent years we have managed to find order even in chaotic phenomena.

Therefore, we wish everyone a good read.

[5] Pennisi E: Alien genes from bacteria helped plants conquer the land. Science, 14 Nov 2019

[6] Kipling R: THE WHITE MAN'S BURDEN. First published in The New York Sun on February 1, 1899 and in The Times (London) on February 4, 1899

I.

LAMARCK HAD NOT BEEN FAR WRONG

BY C. BELLIENI

BEINGS THAT CHANGE FOR THE ENTRY OF OTHER BEINGS INTO THEM

Abstract

This first chapter introduces two terms that are new to many: hybridism and endosymbiosis. We will see that both are important to understand that the evolution of life has not been a linear process, but often there are and have been passages of pieces of DNA or even cellular organs from one being to another; in this way some characteristics of the "donor" being passed to the "recipient". We understand then that the evolutionary process does not depend solely on the survival of the fittest, who prevails over the less gifted; but that we observe not a fight but a donation of genes. This is an important step in the path we are taking.

Charles Darwin was the brilliant discoverer of an evolutionary modality of life on earth. I say of an evolutionary modality and not of evolution, on the one hand because before him many scholars had evaluated and investigated the phenomenon giving various interpretations, and on the other, because after Darwin, knowledge has deepened and explanations have become too complex for a single theory. Then genetics came to help us, and the complexities of life have been analyzed with biochemistry, because life cannot be reduced to unique, simple, and discrete phenomena. Darwin said that species transform to survive: if there is an earthquake or a flood, only those who know how to run fast or swim can survive. But what does this theory tell us about changes that do not lead to a better survival or reproduction? Very little. Why have man's molar teeth shrunk[7] in size over the centuries, just like their feet fingers[8]? To live better, we can answer; but certainly not to survive and reproduce better. We will see in the course of

[7] Jheon AH, Seidel K, Biehs B, Klein OD. From molecules to mastication: the development and evolution of teeth. Wiley Interdiscip Rev Dev Biol. 2013 Mar-Apr;2(2):165-82

[8] Rolian C, Lieberman DE, Hallgrímsson B. The coevolution of human hands and feet. Evolution. 2010 Jun;64(6):1558-68

this work, several examples that Darwin's theory fails to explain as well as possible alternative explanations, certified by scientific experiments, and validated and consecrated by the scientific community. Was Darwin wrong? Certainly, it was not! But like all works of science, revisions and improvements are required.

End of the Dogma of Vertical Transmission of the Genome

Since the late 1970s, two major discoveries have shed new light on who we humans are and how life on our planet has evolved. The first involves a whole category of living things known as archaea (Archaea)[9]. These look like bacteria under a microscope, but their DNA reveals that they are strikingly different from them. The second discovery was a form of hereditary transmission of genetic characteristics directly between subjects of different species called horizontal gene transfer (HGT)[10], while it was believed that DNA was transmitted only vertically, from parents to offspring.

> "Archaea are a group of single-celled microorganisms with distinct characteristics, and constitute 1 of the 3 domains of life, along with bacteria and eukarya. Although they were thought to live only in extreme environments such as hot springs, archaea have emerged as important components of the human microbiome. Despite their potential importance to human health and disease, archaea are studied less than other members of the microbiome, such as bacteria and fungi. The human microbiome harbors a variety of archaeal species from different phyla. Archaeal representatives have been found in various body sites, including the skin, the respiratory tract, the urogenital tract, and the gastrointestinal tract. Human-associated archaeal communities exhibit spatial patterns similar to those of bacteria; notable examples are the predominant signatures of ammonia-oxidizing Nitrososphaeria on the skin, methane-producing (methanogenic) Archaea in the urogenital and gastrointestinal tracts, and

[9] Gophna U, Altman-Price N. Horizontal Gene Transfer in Archaea-From Mechanisms to Genome Evolution. Annu Rev Microbiol. 2022 Sep 8; 76:481-502
[10] Quammen D: Blurring life's boundaries. Antropocene 2018 available at: https://www.anthropocenemagazine.org/2019/06/blurring-lifes-boundaries/

unknown Nanoarchaeota (formerly Woesearchaeota) in the respiratory tract"[11]

The discovery of the archaea gave strength to supporters of the phenomenon of hybridism, which Darwin was unaware of, because in his time it was thought that life was transmitted vertically, that is, from mother-cell to daughter-cell, selecting the appropriate or adaptable ones and making the other ones disappear. Today, hybridism is one of the most accredited hypotheses: eukaryotic cells, that is, animal cells, originated not by natural selection, but by the entry into a bacterium of an archaeon, ready to become an integral element of the new cell through a process called *endosymbiosis*. The discovery of the HGT, as we will see in the second chapter, then questioned the traditional way of thinking about the connection between one species and another: it seems that pieces of the genomes —that is, of the DNA— of all kinds of animals - including humans - have been acquired by horizontal transfer of bacteria or other species. We will deal with the HGT in a bit.

Endosymbiosis, or "from two we become one"

To better understand, let's see here, where the phenomenon of endosymbiosis takes us. Lynn Sagan was a 29-year-old assistant professor from Chicago when she shed new light on a strange old idea about the shape of the tree of life. The tree of life is the graphic representation in the form of a tree, that illustrates how the various branches that constitute the various species have differentiated from an initial trunk.

It is necessary to introduce the concept of symbiosis here, to quickly understand what follows. Symbiosis indicates—from the Greek words *syn* and *bios* meaning "to live together"—the mutual need of two forms of life, where each one is necessary for the other to survive. Lynn Sagan introduced her study in March 1967 with a lengthy article published in the Journal of Theoretical Biology entitled "On the Origin of Mitotic Cells." [12] This radical, surprising, and ambitious paper proposed to rewrite two billion

[11] Duller S, Moissl-Eichinger C. Archaea in the Human Microbiome and Potential Effects on Human Infectious Disease. Emerg Infect Dis. 2024 Aug;30(8).
[12] Sagan L. On the origin of mitosing cells. J Theor Biol. 1967 Mar;14(3):255-74

years of evolutionary history. She presented a series of evidences that supported the strange conjecture that there are "some forms of life" that integrate with other beings and carry out functions within their cells. Adopting the earlier term *symbiosis*, Sagan called that idea *endosymbiosis*[13].

> "The endosymbiotic theory is usually used to explain the origin of eukaryotic cells, but it can also be applied to bacterial cells. For example, Gram-negative bacteria could have evolved via an endosymbiosis between a clostridium and an actinobacterium, implying that their inner membrane is derived from the plasma membrane of the endosymbiotic bacterium, whereas the outer membrane originated from the plasma membrane of the bacterial host. Darwin did not consider the significance of symbiotic associations in his theory of evolution. Moreover, endosymbiosis-mediated fusion of evolutionarily distinct lineages (netlike or reticulate evolution) contrasts with his idea of bifurcating divergence from common ancestors (treelike evolution). Thus, endosymbiotic associations are sometimes treated as examples of non-Darwinian evolution via the inheritance of acquired characteristics (e.g., acquisition of new genes and membranes) or macrogenesis involving 'hopeful monsters' (e.g., protozoans containing red or green algal endosymbionts). Nevertheless, each endosymbiotic association comes under natural selection, resulting in the survival (and reproduction) of only those best adapted to their environments. Regardless of these general evolutionary considerations, available data clearly indicate that endosymbioses have had an enormous impact on the evolution of biosphere of our planet. It seems that a special role in this process was played by the mitochondrial endosymbiosis, which not only enabled the origin of the first eukaryotic cell but also facilitated a dramatic increase in the complexity of the eukaryotic world through the evolution of multicellularity in these cases, the entire genomes of some living organisms - not just individual genes or small clusters - had strayed and been captured within other organisms, which integrated into theirs their entire genome. Thus, both beings could no longer live without each other."[14]

[13] Sagan D. From Empedocles to Symbiogenetics: Lynn Margulis's revolutionary influence on evolutionary biology. Biosystems. 2021 Jun; 204:104386.
[14] Martin WF, Garg S, Zimorski V. Endosymbiotic theories for eukaryote origin. Philos Trans R Soc Lond B Biol Sci. 2015 Sep 26;370(1678):20140330

"This paper presents the theory," wrote D Sagan and Lynn Margulis, that "the eukaryotic cell is the result of the evolution of ancient symbiosis"[15]. Single-celled creatures had entered other single-celled creatures, and at least some of these mating had achieved lasting compatibility by chance and overlapping interests. Eventually, they became more than partners. The incorporated microbes, she argued, had become organelles, that is, functional components of a new compound, like the liver or spleen inside a human being, with fantastic names and different functions: *mitochondria, chloroplasts, centrioles.* They were functional elements of a single new being. From the union of the two a new type of cell was born. Over time, the emerging science of molecular phylogenetics has substantially confirmed their theory of endosymbiosis, that is, that mitochondria and chloroplasts are the result of bacteria captured in cells.

Mitochondria, the organelles of eukaryotic cells, originated as external prokaryotic organisms, introduced into the cell as endosymbionts, about 1.5 billion years ago[16]. Mitochondria would have developed from proteobacteria, the archaea. Proof that mitochondria originated from the ancient endosymbiosis of bacteria is, for example, the fact that mitochondria contain a DNA different from that of the cell nucleus and similar to that of bacteria (a double-stranded circular DNA), personal ribosomes, and a double membrane. Like bacteria, mitochondria do not have histones (regulatory proteins) and their ribosomes are sensitive to some antibiotics (such as chloramphenicol). In addition, mitochondria are semi-autonomous organelles, since they replicate by cleavage, independent of the cell.

Here we are at the dawn of life on earth. It seems that the first evolutionary paths were not only due to the disappearance of the less fit after random DNA mutations, but also to the entry of DNA into cells from outside, in the form of archaea or bacteria that were incorporated, and this incorporation became stable and heritable. This opens the scenario that the evolution of

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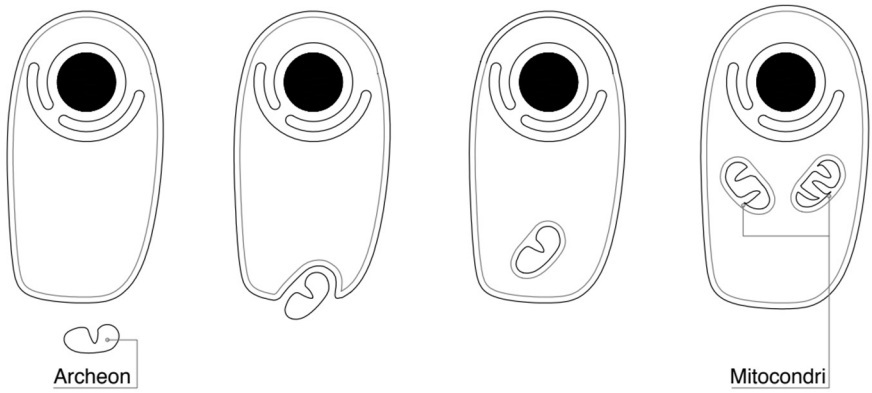
[15] Margulis L, Sagan D. Microcosmos: the universe within us reveals evolution's secrets. Bostonia. 1987 Dec-Jan; 61:55-8

[16] Cavalier-Smith T. Origin of mitochondria by intracellular enslavement of a photosynthetic purple bacterium. Proc Biol Sci. 2006 Aug 7;273(1596):1943-52

life was not only due to competition, but also to collaboration between species.

Figure 1. Transformation of archaea into mitochondria.



Penetrating inside the bacterial cell, the archaeon (or the bacteria) becomes a new and original part of it, for example, mitochondria, with its own DNA, different from that already present in the nucleus of the bacteria.

SPECIES ARE NOT FIXED. THEY COMMUNICATE WITH EACH OTHER

Abstract

This chapter continues the description of this phenomenon: the passage of pieces of DNA from one species to another. We will see how this makes more complex the simplistic picture of evolution seen as a common tree, with a single common ancestor, from which other species differentiated and then others differentiated. We will see how the tree of life has much stranger branches than what was expected a hundred years ago.

We were saying that the Darwinian evolutionary vision represents evolution as a tree, that is, with a trunk (the primordial archaic species), from which the branches (the subsequent species) come to life, then other branches rise and so on. And the way in which subsequent species are born is twofold: a) a random mutation (today we would say "a change in the DNA"), which generates new species; and b) a selection, which causes the species with mutations less suitable for life to die. However, this framework does not foresee that the branches can arise in another way. Which one? We have seen it previously: it sometimes happens that a species "injects" part of its DNA into another species, not causing random mutations, but exchanges, to the advantage of those who receive the piece of DNA that helps them survive; or even that a living being enters into another, and there it begins to live and replicate together with the host's cells. In this latter case, the guest and the host become a single being from two beings which owns - as its greatest advantage - the chromosomal kits of both species that formed it. In short, it seems that certain species communicate with each other by exchanging pieces of genome in a tiny, hidden, but efficient way. This undermines the straight-line vision of evolution We saw an example of this matter, when we have seen the emergence of antibiotics resistance in certain bacteria, due to the mutual exchange of resistance genes.

The implications of this passage of DNA between species, called horizontal gene transfer (HGT), go far beyond the problem of antibiotic resistance. Such implications encompass the whole question of how evolution works – through classical Darwinian mechanisms or not? – and how it has worked for much of the last four billion years.

> "The structure in the Typhi pangenome that is driven predominantly by the gain and loss of mobile genetic elements, confirming and expanding upon known epidemiological patterns, revealing novel plasmid dynamics, and identifying avenues for further genomic epidemiological exploration. With an eye to public health application, this work adds important biological context to the rapidly improving ways of analyzing bacterial genetic data and demonstrates the value of the accessory genome to infer pathogen epidemiology and evolution. Given bacterial evolution occurs in both vertical and horizontal dimensions, inclusion of both core and accessory genetic material (i.e., the pangenome) is a logical step toward a more thorough understanding of pathogen dynamics[17].

The HGT contradicts the belief that bacterial species are fixed and incommunicable. If genes routinely cross the boundary between one species of bacteria and another, in what sense is this really a boundary? By 1999, discoveries had progressed to such a point that Ford Doolittle, a researcher and theorist from Halifax, Nova Scotia, published a review paper in the journal Science that put HGT at the center of a new discussion: whether it is possible classify organisms into a "natural order" by placing them on a schematic tree of life. Doolittle illustrated – literally – the difficulties of the traditional scheme with his hand-drawn illustration of what he called "a reticulated tree."[18,19]

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[17] Peñil-Celis A, Tagg KA, Webb HE, Redondo-Salvo S, Francois Watkins L, Vielva L, Griffin C, Kim JY, Folster JP, Garcillan-Barcia MP, de la Cruz F. Mobile genetic elements define the non-random structure of the Salmonella enterica serovar Typhi pangenome. mSystems. 2024 Jul 26:e0036524.

[18] Doolittle WF. Phylogenetic classification and the universal tree. Science. 1999 Jun 25;284(5423):2124-9.

[19] Doolittle WF. Evolution: Two Domains of Life or Three? Curr Biol. 2020 Feb 24;30(4):R177-R179.

Figure 2

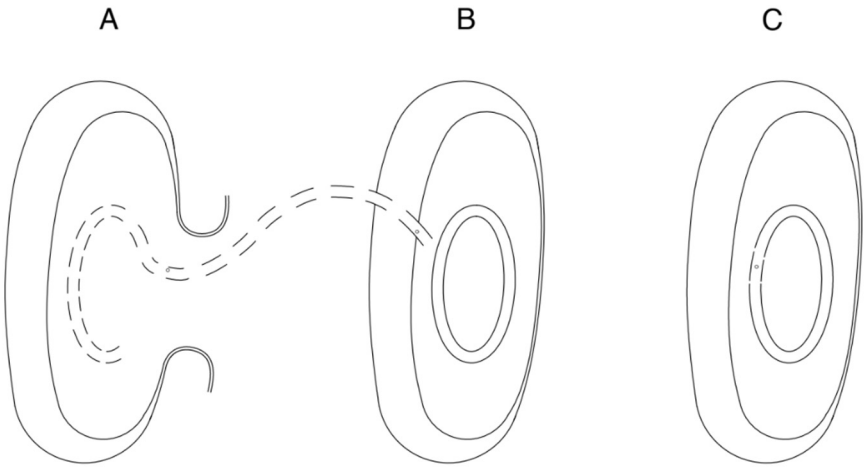
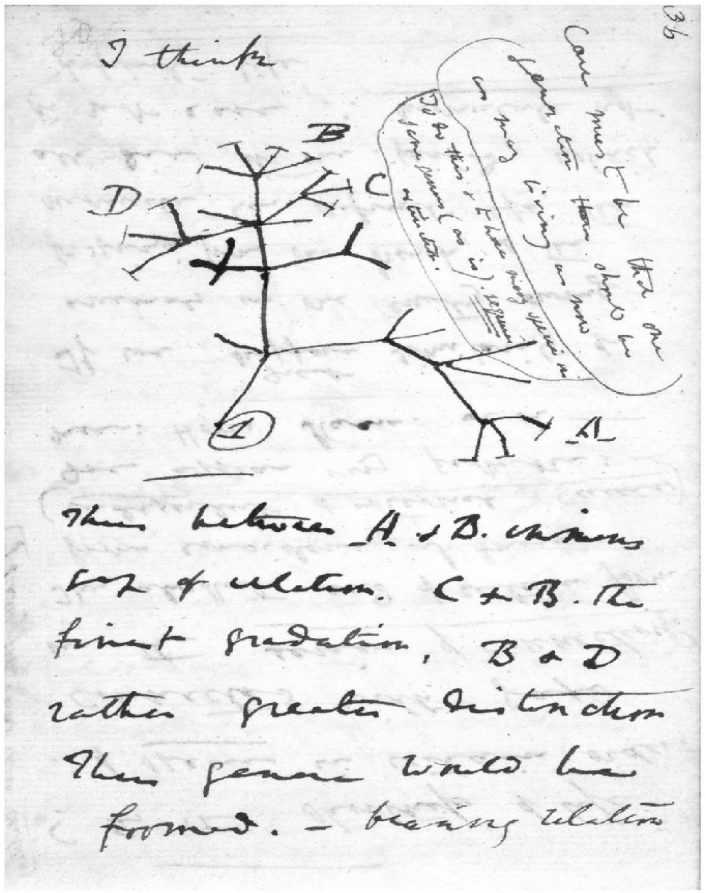


Figure 3 The tree of Life



This is the version hypothesized by Darwin, in which smaller twigs/species start from each branch and take different paths from the other twigs/species due to random selection and the survival of the fittest (figure drawn by Darwin himself).