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The Evolutionary Lottery

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Introduction

It is now established that all living beings, including humans, descend by evolution from a single ancestral form and that this process was largely driven by natural selection, the fundamental mechanism, first discovered by Charles Darwin and independently perceived by Alfred Russell Wallace, whereby forms of life best fit to survive and produce progeny under prevailing conditions obligatorily emerge when several variants compete for the same limited resources. A striking feature of this process is the dominant part played in it by chance, which does so in two distinct ways: first by the mutations that are offered for selection and, next, by the environmental circumstances that condition the selection process.

These facts imply that the extraordinary diversity of living forms on Earth is the outcome of a vast planetary lottery, or, rather, a long string of lotteries, played over almost four billion years and leading, from primitive forms of life, first to bacteria, or prokaryotes, next to unicellular eukaryotes, or protists, and finally to multicellular plants, fungi, and animals of increasing complexity. Humans appear at the very end of the animal line as the products of a lengthy succession of chance events. In the eyes of many of the thinkers who have reflected on the topic, the logical inference from this observation is that the chances of appearance of our species were virtually nil at the start, with as necessary implication the extreme improbability and consequent meaninglessness of the human condition.

The purpose of the present paper is to re-evaluate the validity of this attitude in the light of a closer examination of the data on which it rests.

1. The Rules of the Game

1.1. Mutations

Natural selection depends on the faithful transmission of hereditary traits, to ensure the genetic continuity of selected lineages, and, in a crucially important way, on occasional alterations of this process, or *mutations*, to generate the variants on which selection acts. Such changes may be caused by a number of different factors, including inaccuracies in DNA replication (very rare – one wrongly inserted base in one billion – but nevertheless

significant because of the large size of genomes), rearrangements of DNA sequences by recombination, deletion, insertion, transposition, or other phenomena, chemical alterations of DNA by physical agents, such as UV light, X rays, or radioactivity, by chemical substances (mutagens), or by biological agents such as viruses. In addition, changes affecting other features of DNA chemistry, such as the methylation of certain bases, or the manner in which DNA is associated with proteins in chromosomes may also be involved. These features are covered in the contemporary literature by the term 'epigenetic', which was used previously for non-hereditary changes acquired after birth, in particular in the brain, and is still used in this sense by some developmental biologists and neurobiologists.

A feature common to all mutations is that they are *accidental*. They have specific causes, as just seen, but these causes happen fortuitously and, especially, bear no relation to any foresight of the consequences they may entail.

This notion is important with respect to the theory of 'intelligent design' (ID), which claims that certain critical evolutionary events, ranging from the assembly of cilia and flagella to the formation of eyes and the conversion of reptiles into birds, could not have occurred naturally, but required the operation of some supernatural entity that predefined the outcome and engineered the appropriate genetic changes accordingly. This view differs from strict creationism in that it has no biblical roots and does not negate evolution, but it shares with creationism its call on a supernatural agency. ID is sometimes called 'creationism in disguise' for that reason. It goes back to finalism, or teleology, which is itself closely related to vitalism, the theory, defended by many earlier biologists, according to which life is 'animated' by some kind of 'vital spirit'. Finalism is fuzzier on this issue, claiming simply that life is a goal-directed process, without specifying who or what does the directing. The term 'teleonomy' is sometimes used to express the fact that life has the *appearance* of being goal-directed, but due only to its internal organization and not to any directing agency.

A detailed discussion of ID does not belong in the present paper. Just two comments are in order. First, from the purely scientific point of view, it is readily shown that many of the claims made by ID advocates rest on oversimplified views of the evolutionary process, which ignore factors such as the immense times taken, the circuitous pathways followed, and the large numbers of individuals and generations involved, as well as much of the recent information provided by molecular phylogenies. In fact, plausible explanations have already been offered for several of the allegedly unexplainable evolutionary processes, the formation of eyes, for example. Next, and more importantly, ID is simply *not a scientific theory*. It disqualifies

itself as such by its assertion of unexplainability. Scientific research is based on the postulate that events are naturally explainable. Whether this is true or not is immaterial. There can be no research without this basic assumption. Do away with it, and you can close your laboratory.

The term 'postulate' is important in the above consideration. Science is not entitled to affirm, as is done by some scientists, that everything is naturally explainable. Until everything is explained, such a statement is unwarranted. Subject to this caveat, imposed by scientific objectivity, it must be recognized that spectacular successes have been achieved under the aegis of the naturalist postulate and continue to be achieved at an ever increasing pace. These successes certainly strengthen the postulate enormously and encourage further research under its guidance.

By definition, natural selection can act only on the variants that are offered to it. Better solutions to an environmental challenge may be possible. If they are not provided, they will not be realized. Selection is limited by the kinds of variants that are offered to it by chance

This obvious fact raises the question as to how many of all the possible variants are included in the set provided by chance. At one end of the spectrum, if the set is complete, selection will bring out the best in reproducible fashion; the final outcome will be *optimization* with respect to the environmental challenge faced. At the other end, if only a very small subset of the possible variants is provided, whatever happens in reality will depend on the composition of this subset; the process will be ruled by *contingency*.

For a long time, the second possibility was the ruling opinion, though rarely expressed in quantitative terms. It was simply taken as self-evident that, because of the involvement of chance in the course of evolution and of the vast number of possibilities open to it, this course must by necessity have been dominated by contingency. This view was eloquently defended and propagated by many evolutionists of the past, including George Gaylord Simpson, Ernst Mayr, Jacques Monod, François Jacob, and Stephen Jay Gould, to mention only a few. Coinciding with the rise of existentialism, especially in France, this message from science was interpreted as affording strong support to the philosophy of the absurd then in vogue.

Little attention was paid to the fact that chance always operates within a set of *limits*. Whether at heads-or-tails, roulette, or the lottery, the number of possibilities is finite and given occurrences become increasingly probable as more trials are made. Thus, even a seven-digit lottery number has a 99.9% probability of coming out if 69 million drawings are made. Admittedly, lotteries for gain don't function that way. But the evolutionary lottery is different. Because of the enormous times and large number of individuals

involved, also because of the intrinsic constraints of genomes, many specific mutations have a greater probability of occurring than intuition would lead one to predict.

Several facts support this contention. Take *mimesis*, for example, the property whereby some animals closely resemble their surroundings and thereby evade predators better than those not similarly protected. Acquisition of this property in one shot is clearly impossible. An insect cannot suddenly become almost indistinguishable from the leaf or branch on which it sits; a fish cannot suddenly resemble the sand or pebbles on which it rests. The process, if it occurred naturally, as must be supposed, must necessarily have gone through a large number of stages, at each of which the animals became a little more similar to their environment, sufficiently so to enjoy some selective advantage. It is evident that these stages could not have occurred if the necessary mutations had not been provided each time.

Another impressive fact is the frequency of evolutionary *convergence*, the independent acquisition of the same adaptations to given environmental challenges. Hundreds of examples of this remarkable phenomenon, from saber-toothed tigers to anteaters, have now been recorded, prompting members of the younger school of evolutionists, such as Simon Conway Morris and Richard Dawkins, to defend the view of a largely obligatory and reproducible evolutionary history, in direct opposition to their predecessors.

Note, however, that the view remains conditional: same circumstances, same result. But what if the circumstances change? Here, contingency comes back to the forefront, by linking the history of life to the vagaries of environmental changes. This is the second chance-dependent factor in natural selection.

1.2. The Environment

Natural selection is critically dependent on the prevailing environment. The features that are selected are those that are conducive to, or, at least, compatible with, the survival and proliferation of the individuals and populations involved *under the conditions* to which they are exposed. Change those conditions and the selective response will be different.

An obvious implication of this fact is that evolution must have been molded by the environmental history of the Earth, which makes it unique, whatever the number of life-bearing planets in the universe, as no planet can have exactly the same history. True enough. But how different can one expect the two to be?

Here, a basic distinction must be made between two ways in which the environment plays a role. In one, which may be called *instructive* (with no connotation of design), the environment defines the selected property. Thus,

adaptation to certain external conditions, such as dryness or cold, is clearly influenced by the environment, desert or polar ice field, to which the organisms are exposed. Mimesis is another obvious example of environment-dependent evolutionary change. Without green leaves, no insect would become leaf-like. Most of the innumerable details that define biodiversity fall in this category, reflecting the enormous variety of environmental conditions that have affected natural selection. In this respect, life on our planet is undeniably unique.

The other way in which the environment may affect natural selection may be termed *facilitating*: the elicited phenomenon is intrinsically mandated by the stage reached by evolution, with the environment acting simply to provide the trigger for this potential to materialize. A typical example of such a happening is the rise of the mammals after some global catastrophe, presumably caused by the fall of a large meteorite on the Yucatan Peninsula in Mexico about 65 million years ago, cleared the way for them by wiping out the dinosaurs and many other forms of life. One is clearly not dealing here with an adaptation to a specific environmental situation, but rather with the actualization of an existing propensity by an environmental accident. Indeed, it is most likely that the dinosaurs were fated to disappear in any case, together with the luxurious vegetations from which they drew their subsistence, and that, if not the fall of a meteorite, some other accident would have precipitated their extinction.

Hominization, launched 6-8 million years ago by an upheaval believed by some anthropologists to be the separation of the savannah from the forest by the Great African Rift, which provided selective value to bipedalism and the associated brain expansion, could be another example of environmental facilitation of a latent evolutionary step. The process, once initiated, developed so rapidly – a quadrupling of brain size in only a few million years – as to suggest that the step involved was long present in potential form, awaiting only an environmental trigger to be precipitated. Had the Rift not split the African continent, assuming it played a role, some other accident could have propelled some chimpanzee-like primate on the way to becoming human.

It is possible that many decisive events in evolution belong to this category, imposed by the inner constraints of the evolutionary process and merely triggered into happening by environmental factors. Precise information on this topic is lacking, but the possibility it evokes must be kept in mind as it implies that the history of life on Earth, although subject to the vagaries of environmental conditions, may in its main lines, have followed a course largely imposed by properties, potentialities, and constraints inherent to the living process.

2. A Fresh Look at Evolution

2.1. The Evolutionary Lottery

Our view of evolution as a huge planetary lottery has not changed. What has changed is our appreciation of the probability of a lucky number coming out. Chance, we have learned, does not exclude necessity.

Two factors have to be reconsidered. First, mutations, although governed by chance, are not as 'chancy' as was believed. Because of the immense number of opportunities that are provided on the evolutionary scale, the mutations due to be most effective under the circumstances are often almost guaranteed to occur at some stage, thereby introducing optimizing necessity into the process.

As to the part played by the environment in the lottery, it depends on the nature of the affected event. The role of environmental contingencies is clearly decisive in the myriad instances of adaptation to specific geological, geographical, climatic, ecological, or other adventitious circumstances. Environmental conditions tend to be less decisive and more often merely facilitating when it comes to major transitions. In this new perspective, evolution appears as intrinsic to the living process, with every major step somehow mandated by the stage that preceded it, all the way from the earliest living forms up to humankind.

As to the earliest living forms themselves, I have argued elsewhere that, because of the deterministic nature of chemical events and of the frequency of optimizing selection, the processes that initiated life on Earth must have been imposed by the physical-chemical conditions that prevailed on the prebiotic Earth. Given those conditions, life as we know it – including ATP, RNA, DNA, base pairing, the genetic code, protein enzymes, and lipid membranes – was virtually bound to appear.

The view that emerges from those considerations is of life and mind as *cosmic imperatives*, rather than improbable products of random chance. The reason supporting this statement does not lie in any finalistic or 'anthropic' view of the universe, seen as having been created for the *purpose* of giving rise to life and mind, but rests simply on a *factual* assessment of the events that have governed evolution, including the appearance of humankind. The universe just happens to be such as to necessarily give rise to life and mind. Some observers may derive a theistic view from this realization. Others, however, may content themselves with seeing it as a manifestation of *ultimate reality*.

2.2. The Tree of Life

Evolution is often pictured by a tree rooted in the early chemical phenomena that have given rise to the first living cells, almost four billion years

ago. Like all trees, the tree of life has grown in two directions: vertically and horizontally. The vertical direction, delineated by the trunk and master branches, has given rise to increasing *complexity*. The horizontal direction, traced by the countless lateral ramifications that have sprung at each level of complexity, has led to increasing *diversity*.

The main conclusion to be derived from our new appreciation of evolution is that contingency has affected mostly the horizontal ramifications of the tree of life. On the other hand, the vertical extensions of the tree appear as strongly driven by the inner pressures and resulting constraints created by the evolutionary stage reached, waiting only for some environmental trigger to be set in motion.

2.3. Extraterrestrial Life

A corollary of the above considerations is that, if another Earth-like planet should display conditions conducive to the development of forms of life similar to those that started life on Earth, the resulting tree would most likely differ greatly from the Earth tree in the details of its canopy, but could show a similar vertical structure. Given enough time, the appearance of human-like intelligent beings could even be contemplated.

These points are relevant to the great interest accorded in recent years to the search for life-bearing extrasolar planets and for signs of extraterrestrial intelligence. Such searches are justified by what is known of evolution and by the very large number of sun-like stars believed to exist in the universe (on the order of $3x10^{21}$). We are not likely to be unique with so many opportunities provided for intelligent life to arise. The problem is that most of those countless planets are totally out of reach of present technologies. Even those that have been identified in our nearest neighborhood could not reveal telling signs of life to existing instruments, except, possibly, for the presence of molecular oxygen (not found so far), which, on Earth, is a product of life. What the future will bring can obviously not be anticipated.

2.4. The Future

A major question raised by the above considerations is: Will the tree of life continue growing as it has done before, losing branches and extending new ones in the horizontal direction to create more diversity, and, especially, progressing vertically towards increasing complexity? A priori, there seems to be no valid reason for excluding such an eventuality. There is plenty of time for it. According to astronomers, the Earth should remain physically able to support life for at least 1.5 billion years, perhaps as long as five billion years, when the sun is expected, its energy resources exhausted, to convert

into a red giant, abolishing all possibilities of life on surrounding planets. As to the plausibility of such an event, only human hubris could cause us to rule it out. In all objectivity, there is plenty of room for improvement in human nature. We have no valid reason for considering our advent as the crowning event in evolution. Our recent past is landmarked by the appearance and extinction of hominid species of increasing cranial capacity and, presumably, greater mental power. The remarkable tendency of the human brain to grow bigger and more powerful is presumably still extant, awaiting only the anatomical and developmental changes needed to make it possible for it to manifest itself.

Present circumstances are, however, very different from those that have allowed the appearance of our species and the extinction of our forebears. Instead of small bands subsisting precariously, often completely separated from each other and capable of evolving each in isolation, humanity has invaded the entire surface of our planet, filling it with more than six billion individuals connected by a dense network of communications. Our extinction and replacement by some sort of 'übermensch' would require a massive planetary disaster too horrible for even our imagination to picture. The rise of a better fit species on such ruins would have nothing in common with the displacement of the Neanderthals by our species.

There is an even more fundamental difference. This dire fate is not ineluctable. For the first time in the history of life on Earth, a species has appeared that is not slavishly subject to natural selection. Thanks to their superior brains, humans have acquired the ability to do what natural selection is incapable of: look beyond the immediate present, foresee the outcome of possible future events, elaborate plans as a function of those predictions and responsibly act accordingly, even if it means sacrificing immediate benefits for a greater, later good. The future of life and, with it, of humanity itself, thus depends on the wisdom with which coming generations will make use of this ability.

Summary and Conclusion

- There is less chance, and more necessity, in evolution than has commonly been believed, not because of the intervention of some purposeful influence in the process, but because of the frequency of selective optimization and of the intrinsic constraints of the living process.
- The horizontal growth of the tree of life in the direction of increasing diversity has been largely contingent on environmental peculiarities not expected to be repeated on another planet. Its vertical growth toward

increasing complexity, however, seems to be more obligatory and commanded by the attained evolutionary stage.

– With the advent of humankind, natural selection has ceased to be the only driving force of evolution. Human foresight and ability to purposefully act against natural selection have changed the rules of the game. Henceforth, the future of life and that of humanity itself will depend, at least partly, on human responsibility and wisdom.