Cellular Origin, Life in Extreme Habitats and Astrobiology 23

Liz Swan
Richard Gordon
Joseph Seckbach *Editors*

Origin(s) of Design in Nature

A Fresh, Interdisciplinary Look at How Design Emerges in Complex Systems, Especially Life

Springer

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Cellular Origin, Life in Extreme Habitats and Astrobiology

Volume 23

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DEDICATION

For my husband, Eric Swan, and for the little piece of nature we gave origin to, Freeman Jack Swan.

–Liz Swan

Dedicated to my wife Fern, our children, and grandchildren in the Seckbach clan. And in addition, to the late botanical professor, Yaakov Leshem (Bar Ilan University, Ramat Gan, Israel), who guided me on the publication path.

–Joseph Seckbach

For Diana Gordon, artist, on the occasion of her 90th birthday, and her great grandson Luke Hunstad, of as yet undesigned aspirations, on the occasion of his first.

–Richard Gordon

INTRODUCTION TO ORIGIN(S) OF DESIGN IN NATURE [ODIN]

The origin of life is still a mystery, but the results of design are visible on Earth and in the universe. Design, including the emergence of many evolutionary lines and diverse ecosystems, is familiar to all of us. We recognize design everywhere; interior decorating, garden landscaping, urban planning, and industrial uses are only a few examples. There is also design in social sciences, intelligence, and other manifestations of life.

In this volume, we deal with the *Origin of Design in Nature* (ODIN), with its 42 authors discussing various aspects of this topic. The aim of the authors is to determine whether all phenomena in nature originated spontaneously or under intelligent guidance and creation. One might visualize the wonderful internal structure of atoms, molecules, cells, organs, organisms, and the universe itself and its galaxies and ask, "How did all this come about?" or ask, as stated in the Bible, "Who created all of those?" (Isaiah 40:26). The articles in this book range from a purely scientific approach to the traditional act of creation as seen by religions wherein there is a biblical account for the emergence of life (in the first chapters of Genesis). These statements need not necessarily contradict the scientific approach. Indeed, natural designs can be seen all over, but their origin has led to lively and constructive discussions, as the present book demonstrates. This volume (number 23 of *COLE*) provides an interdisciplinary look at how design emerges in complex systems.

The target audience of this volume is graduate-level students and professional humanists and scientists in philosophy of science, astrobiology, evolution, dynamics, and complex systems.

We acknowledge all the contributors for their chapters and among them the patient "early birds." Special thanks are due to Professor Julian Chela-Flores (ICTP, Trieste, IT) who is always our "right hand" within the new volumes of COLE books and to Fern Seckbach for her constant linguistic and style assistance. Appreciations are due to the reviewers, to external referees who read all the chapters and gave their comments. Last but not least, thanks to Maryse Walsh and Melanie vanOverbeek—the Springer team.

Joseph Seckbach The Hebrew University of Jerusalem, Jerusalem, Israel

FOREWORD

The main theme of *Origin(s) of Design in Nature: A Fresh, Interdisciplinary Look at How Design Emerges in Complex Systems, Especially Life* is especially relevant for the development of the life sciences. Charles Darwin's two theories of evolution remain the cornerstones of our discussion (Mayr, 1991): evolution by natural selection and the common descent of all life on Earth. Indeed, life on Earth is an example of life that can be understood in terms of evolution by means of natural selection. Darwin's second theory is intimately related to the search for the origin of life on this planet.

We should take a closer look several issues that have been discussed for a considerable time in the context of the wider problem: design in nature (Chela-Flores, 2011). This topic has a long history going back to ancient Greece. However, in modern times, we may begin with the work of William Paley (1743–1805), who was an Archdeacon and Doctor of Divinity at Cambridge University. His writings were highly respected in the Anglican order. His *Horae Paulinae* was written in 1790 specifically to prove the historicity of the New Testament. Another famous book was *View of the Evidences of Christianity* (1794), a text that was standard reading among undergraduates during Charles Darwin early university education. However, his best-remembered book is *Natural Theology,* which played an important role in the early stages of the establishment of Darwin's arguments.

Paley presented some observations from nature intending to prove not only the existence of a grand design, but more importantly also, in his book, Paley attempted to prove the existence of an intelligent designer. The famous quotation that follows is at the beginning of his book:

> *Suppose I found a watch upon the ground, and it should be enquired how the watch happened to be in that place…When we come to inspect the watch, we perceive that its several parts are framed and put together for a purpose…the inference, we think, is inevitable, that the watch must have had a maker…*

This argument can be traced back to classical times, but Paley's defense of it in modern times was influential in the nineteenth century dialogue between science, philosophy, and theology. One of the fundamental steps in the ascent on man toward an understanding of his position in the universe has been the realization that natural selection is indeed a creative process that can account for the appearance of genuine novelty within science frontiers, independent of a single act of creation, but more as a gradual accumulation of small successes in the evolution of living organisms. This is a point that has been defended by many of the founders of Darwinism, most recently by others, who refer to an analogy with artistic creation. The creative power of natural selection arises, according to Jacques Monod, as an interaction between chance and necessity (a phrase that became familiar thanks to his very popular book *Chance and Necessity*).

With Francisco Ayala, for instance, we may consider a painter who mixes and distributes pigments over a canvas (Ayala, 1998). The artist does not create the canvas and pigments, but the painting is the creation of the artist. A random mixture of pigments could not have created Leonardo's *Mona Lisa*, or at least the probability is infinitesimally small. This underlines the fact that natural selection is like the painter—it is not a random process. The scientific approach to rationalizing the complexity of the human eye, for instance, has shown us that it is the result of a nonrandom process, namely, natural selection. It is somewhat surprising, however, that what has just been described, Darwin's straightforward (but brilliant) thinking, has led to so much controversy at the frontier of science and the humanities. In the future, unfortunate controversies will gradually disappear, due to recent work, and I am convinced, also, due to many of the chapters that make up the present book.

I would like to end this brief Foreword with some thoughts that may help to turn bitter debates into constructive dialogues helping our culture on both sides of the humanities/science frontier. Two terms from the humanities are relevant for our considerations. Firstly, exegesis is a critical explanation of any text, but more often it is restricted to a critical interpretation of a religious text to discover its intended meaning.

On the other hand, hermeneutics refers to an approach arising from the method of interpretation. When we apply it to religious texts, it is precisely exegesis, but when we apply it elsewhere, it coincides with other approaches to interpretation. For example, when we apply it to literary texts, the interpretative method is known as philology, whereas when it is applied to legal texts, it is known as jurisprudence (Changeux and Ricoeur, 2000). The objective of hermeneutics is not to reach some ultimate truth, but to get deeper insights into thoughts and symbols, to reach within our limitations the best and most exact position possible.

Hermeneutics is in principle relevant to all forms of communication and expression: written, verbal, artistic, physiological, and sociological. But the physical, Earth and life sciences have not been included in this range of disciplines. For a good reason, we may add since science within its frontiers—defined by Galileo—has to be judged by its close adherence to the results of repeatable experiments, or by careful repeatable observations. As scientists, we are not qualified to cross over into the domain of the humanities, as its various branches are, unlike scientific disciplines, not based on theories supported by experimental data or supported by observations shared by a large number of independent scientists. And very often, when the frontier is crossed in the opposite direction, lamentable misinterpretations occur. In general, frontier crossing without the necessary background and respect for the special characteristics of science, as well as for the special characteristics of the humanities, lie at the root of most of the misinterpretation of Charles Darwin's monumental contribution to science, which is the basis for understanding design in the life sciences.

Humanists have an advantage on scientists, in the sense that with the long traditions of exegesis and hermeneutics, going back to the emergence of Western civilization, only misinformed interpretation of the Holy Books of the Abrahamic religions lead to unnecessary defense by the pious in view of a presumed contradictions raised by rational thinking. More damaging still is the vision of a (fortunately) small group of highly prolific scientists—extraordinarily competent in their own special scientific field of expertise—but without a thorough mastering, or even with complete lack of respect for the specific merits and methods of the humanities. Without hesitation, or meditation, sometimes, the scientific frontier has been crossed into areas of the humanities that are best left to the specialists of philosophy and theology, where the scientific method is well beyond its range of validity. Fortunately, excellent clarifications of these extrapolations have appeared in competently written literature by well-qualified humanists (Cornwell, 2007).

With its many chapters by our distinguished authors, the present book is making a genuine attempt to provide arguments related to design in complex systems, including life. We are convinced that these pages will define more sharply the all-important frontier of science and the humanities. This volume is intended to serve as a stepping-stone to fully appreciate, and to interpret correctly, the humanistic implications of one, if not the most, transcendental contribution to science: Darwin's publication in 1859 of his seminal book *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life.*

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PREFACE: ODIN

Design as evidenced by the presence of ordered complexity fills nature. Most especially, but not exclusively, this is manifest in the biosphere. The conundrum we confront in this book is from where did and does this complexity, this functionally effective design, arise, and how does it maintain itself? Does the emergence of design demand that there be a designer? From the finely tuned structure of an atom, through the eloquent molecular biology of a microbe, to the intricacy of a brain with the surprise emergence of consciousness, design is obvious. Just as it is with William Paley's proverbial watch found on a path. But unlike a watch which has no ability to remake and refine itself, nature seems imbued with a drive, a force that pushes it to ever-increasing complexity. This upward direction is so obvious and ubiquitous that we, being one of the products of this drive, may fail to internalize the implications. Nature has a direction.

Though the universe, as it expands outward, races toward its own heart death, in specific, favored locations where abundant sources of energy remain, complexity abounds. The forces of nature cannot defeat increasing entropy on the scale of the universe. This is one of the unyielding laws of nature. But locally, those same forces can out maneuver the drive toward chaos, concentrate the energy, and ultimately give rise to life and brain and mind.

"I don't know who discovered water, but I'm pretty sure it wasn't a fish." So wrote Marshall McLuhan in The Medium is the Massage. Why would not a fish be the first to discover water? Simply because it is their total milieu. We are not so different. We live so totally in a world of complexity and consciousness that only by intellectual effort do we question its origins. Let us do that.

The first step toward sentient life is the creation of existence, the universe. We might ask why there is existence, but of course if there were nothing, we would not be here to ask. So, let the need for existence be a given. An eternal universe (i.e., no creation) presents technical problems such as accounting for the residual useful energy currently present in an infinitely old universe. If the universe is not eternal, then we need a force to produce it. The current best estimate is that a quantum fluctuation in a virtual vacuum brought the universe into being.

Our concept of time begins with the universe. Therefore, the laws of nature, of which quantum phenomena are a part, must predate time, be timeless at least in the human conception of time. This has extraordinary implications. As Ed Tryon, who first proposed this idea almost 40 years ago, recently observed, "If matter and energy are the result of a spontaneous creation [i.e., a quantum fluctuation], then matter and energy are not fundamental. They are manifestations of underlying the laws of nature. Ultimate reality would then be the laws of nature." The world we discover is the product of ethereal eternal forces of creation.

The laws of nature as they act within this world which they created have a plethora of complexity enhancing and ultimately life-enabling traits. To name just two, we have the following: the Pauli Exclusion Principle and de Broglie's revelation of the wave characteristics of matter. Remove these from our milieu and chemistry ceases, stable molecules never form. Together, along with the twist of nature that produced protons and electrons with identical but opposite electrical charges even though the proton has a mass 1,837 times that of an electron, it allowed chemistry to proceed. The fundamental requirements for life were present, not only at the creation, but if Ed Tryon's hypothesis is correct, the needs for eventual life were present even prior to the creation, couched within the laws of nature.

Fourteen billion years had to pass before the expanding universe became amenable to life as we know it. But once the life-friendly platform we call Earth emerged, the right-sized planet located in the narrow habitable zone around the right-size and right-age star, our sun, in the life-friendly region of a spiral galaxy, the Milky Way, life burst forth. On Earth, the oldest rocks that can bear fossils of life have them. And noting that the size and shapes of these primordial fossilized microbes are spot-on matches of their modern descendents, it is likely that their genetic engineering was similar to that found throughout today's biosphere.

DNA, the universal (or at least earthly)-coded blueprint of life seems to have been ubiquitous from the very beginning of life. Now that is surprising because DNA is a totally digitally coded system. Just as dot dot dot dash is meaningless to anyone not familiar with the Morse code (It signifies the letter "v.") and just as dot dot dot dash holds absolutely no similarity to the letter for which it stands, so the four-digit code of DNA, the four nucleotides, bear no physical relationship to any one of the 20 amino acids for which they code by varying their arrangement on the DNA helix. All life is a variation on this theme. And life appears to have gone digital from its inception. With that majestic innovation, the potential for variation became vast.

Darwin was correct when he wrote in the closing lines of The Origin of Species, "… from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

But how did it happen? Is all this the work merely of the laws of nature, as Professor Tryon wrote, or is there a more cosmic force at work nudging those laws to facilitate the emergence of forms "most beautiful and most wonderful?"

For this, we might turn to the complete quote of the closing sentence of Darwin's "Origin," as it appears in every edition except the first (including the second edition which appeared a mere 5 weeks after the first edition). "There is a 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 whilst this planet has gone cycling on according to the fixed laws of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

Has Darwin correctly identified the ultimate origin of design in nature? Would that not be a surprise!

End

Gerald L. Schroeder College of Jewish Studies, Jerusalem, Israel

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PART I: ORIGIN OF DESIGN

Lineweaver
Egan
Grandpierre
McGrew

Nature and Man – cooperation in design. This photo of a bush shaped like an elephant was taken by Joseph Seckbach at the Utopia Park at Kibbutz Bachan near the city of Netanya (Israel).

Biodata of **Charles H. Lineweaver** and **Chas A. Egan**, authors of "***The Initial Low Gravitational Entropy of the Universe as the Origin of Design in Nature***."

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THE INITIAL LOW GRAVITATIONAL ENTROPY OF THE UNIVERSE AS THE ORIGIN OF DESIGN IN NATURE

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Great fleas have little fleas upon their backs to bite 'em,
And little fleas have lesser fleas, and so ad infinitum.

—Augustus De Morgan

Big whirls have little whirls that feed on their velocity,
and little whirls have lesser whirls and so on to viscosity.

—Lewis Fry Richardson

1. The Second Law of Thermodynamics: Entropy Increases

Life and other far-from-equilibrium dissipative structures such as galaxies, stars, planets, convecting mantles and hurricanes, increase the entropy of the universe (Lineweaver and Egan, 2008). They need gradients of density, temperature, chemical potential, pressure, humidity or luminosity to form and survive (e.g. Schroedinger, 1944; Schneider and Kay, 1994; Schneider and Sagan, 2005; Kleidon, 2010). Each one of these gradients can be traced back to other larger-scale gradients which are the sources of free energy.

For example, the Sun is hot (~6,000 K) while the Earth is cool (~290 K). Since the Earth is a sphere, the equator receives more sunlight. Equatorial sunshine evaporates the oceans and warms the tropics. Large-scale hemispheric temperature and humidity gradients are set up and maintained by sunlight. These gradients drive winds, thunderheads and hurricanes. Water evaporates, goes up into clouds, gets blown over land and rains down on mountains. We convert the resulting difference in gravitational potential (gravitational gradient) into a voltage gradient using a turbine in a hydroelectric power station. With a windmill, we convert the momentum gradient of the wind into a voltage gradient. Then with heaters, refrigerators and air conditioners, we convert the voltage gradient into conveniently placed small-scale thermal gradients – which then dissipate into waste heat. Each conversion is irreversible in that it is dissipative and produces waste heat. Physicists call the non-existent exceptions to this rule dissipationless, reversible processes.

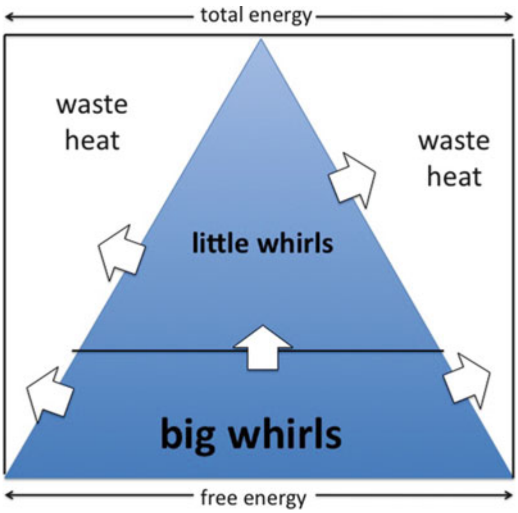

Figure 1. The dissipation of free energy. Starting at the bottom, the free energy of a few big whirls gets converted into many more little whirls and dissipated into waste heat. The total energy (= width of figure) is conserved. Big whirls turning into little whirls which turn into waste heat is a simple way to understand the more complicated picture of Fig. 2.

The conversion of free energy into waste heat can be similarly described for all processes (Kleidon, 2010). While Earth-bound climate scientists take the free energy from the Sun as a given, astrophysicists can dig deeper into the origin of free energy. Figure 2 is a more explicit version of Fig. 1 that tries to do that.

Just as big atmospheric whirls on Earth dissipate into little whirls and soon become microscopic waste heat, on a cosmic scale, the energy of the universe – initially stored in a small number of degrees of freedom – dissipates as it spreads out over a larger number of degrees of freedom (Fig. 3). In this way, free energy is converted into waste heat by dissipative structures, and the overall ability to do useful work diminishes. Energy is conserved, but distributing it over a larger number of degrees of freedom makes it less extractable to do work. This is how entropy increases (Jaynes, 1984).

Since there are no net flows of energy between large (>100 Mpc^3) comoving volumes of the universe, energy is conserved (first law of thermodynamics). This constant energy is represented by the constant width of (Figs. 1, 2, and 4). The second law of thermodynamics (entropy increase) is represented by the diagonal lines of the pyramid – the boundary between useful free energy and waste heat. The relationship between the Helmholtz free energy F, total energy U and waste heat TS (T: temperature, S: entropy) can be written as

$$F = U - TS, \tag{1}$$

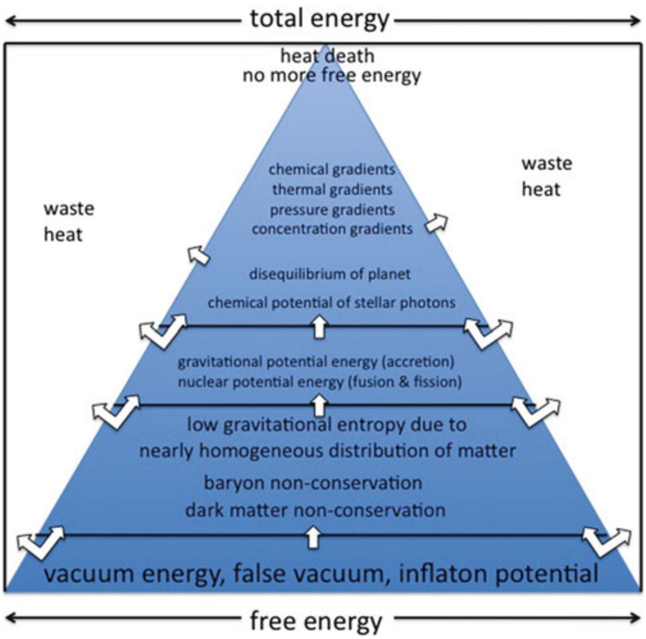

Figure 2. Trophic pyramid of free energy production – a more explicit and comprehensive version of Fig. 1. The free energy available at one level comes from the level below it. The width of the pyramid is the amount of free energy available. As free energy spreads into more and more processes at smaller and smaller levels, waste heat is produced as dissipative structures (*white arrows*) feed off the steady state disequilibrium. Dissipative structures can also transfer free energy to other structures. For example, stars provide high-energy photons that power the thermal gradients that make winds blow and evaporate oceans, driving the hydrological cycle, and energy for plants, which produce waste heat but also oxygen and apples (the free energy of chemical redox gradients) for heterotrophs. The lower levels are prerequisites for the life above it. Far-from-equilibrium dissipative structures traditionally classified as life forms (FFEDSTCALFs) are restricted to the top level. The narrowing at the top of the pyramid represents the decreasing amount of free energy available at higher trophic levels (Figure modified from Lineweaver and Egan, 2008).

or in words,

$$\text{Available work} = \text{Internal energy} - \text{Waste heat}.$$

Figure 4 is just a version of Fig. 2 annotated with Eq. 1. Taking the differentials of Eq. 1 for a system in which total energy is conserved and temperatures are not changing (i.e. T_{Sun} = constant ~ 6,000 K and T_{Earth} = constant ~ 290 K) yields

$$dF = -T\,dS, \tag{2}$$

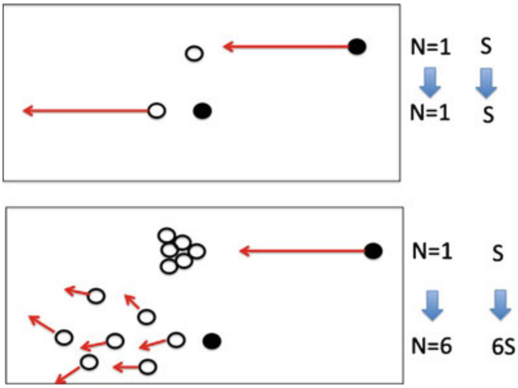

Figure 3. Entropy, *S*, increases when the number of degrees of freedom over which the energy is spread increases. In the *top panel*, the kinetic energy of one *black ball* is transferred to the kinetic energy of one *white ball*. The number of degrees of freedom over which the energy is spread (and thus the entropy) is constant. In the *bottom panel*, the kinetic energy of the *black ball* is transferred to six *white balls*. The number of degrees of freedom increases from 1 to 6, and the entropy increases from *S* to 6*S*.

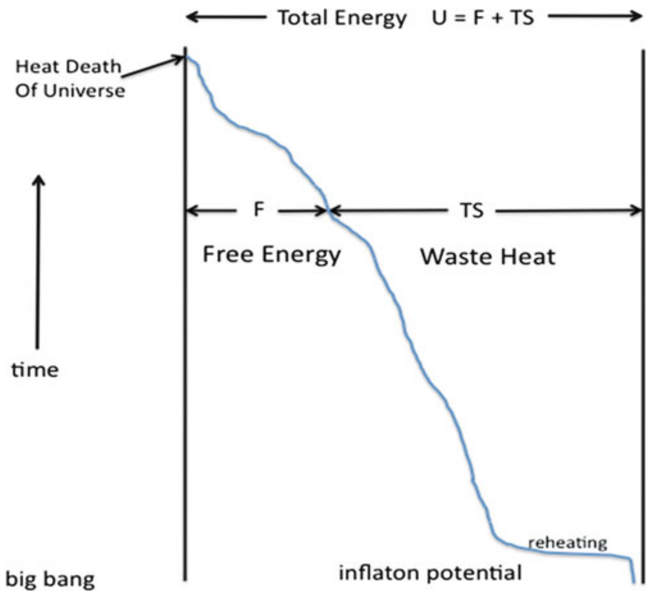

Figure 4. We can separate the total energy U into useful free energy F and waste heat TS (since $U = F + TS$). With a constant U, starting at the big bang at the bottom of the figure, entropy increases and F decreases. As time goes by, more and more of the initial free energy is converted into waste heat.

which means that in such a system, all extracted free energy dF is eventually converted into waste heat TdS.

The various forms of free energy are usually written as (Bejan, 2006; Kleidon, 2010)

$$(dF = pdV + \phi dm + \boldsymbol{v} * \boldsymbol{dp} + \Sigma_i \mu_i \, dN_i) \tag{3}$$

where p is pressure, V volume, ϕ gravitational or electric potential, m mass or charge, **v** velocity vector, **p** momentum vector, μ_{i} chemical or nuclear potential of species i, and N_i number of particles of species i. For each pair of variables, the first is an intensive quantity, while the differential is of an extensive quantity. The extractable work comes from the gradients of the intensive variables (gradients in pressure, gravity, momentum and chemical potential). Work can be extracted from macroscopic gradients, i.e. gradients of a scale larger than the microscopic particles (atoms, molecules, charges) which get pushed around or fall through the gradients and importantly provide the large number of degrees of freedom for waste heat. A pressure gradient (think pistons of a steam locomotive or internal combustion engine) does "pdV" work. A gravitational potential gradient can do work when a mass, dm, falls (hydroelectric power plant). If the potential is from an electric field, work is done when a charged dm falls from high potential to low potential (inside a kitchen appliance for example). In the presence of a velocity gradient, momentum exchange does work (windmill). Work can be extracted from a chemical potential gradient (concentration gradient) when a particle species does work by going from high concentration to low concentration (lithium batteries, osmotic pressure engines, metazoan digestive tracts). Jaynes (1984) describes the relationship between the Carnot efficiency of a heat engine and the efficiency of muscles and insightfully relates both to work and the number of degrees of freedom.

2. Spiegelman's Monster

A differentiated and information-rich terrestrial environment applies selection pressure on whatever is existing or evolving in that environment. If the environment is hot, then molecules and membranes that can withstand the heat survive. On Earth-like planets, temperature, humidity, pH and surface chemistry vary both spatially and temporally. Any life form in these environments has to be able to survive the conditions and maintain enough variability in the population to be able to adapt to the changing condition. Thus, both the phenotypes and the dispersion of the genotypes are selected by the environment. The evolution of the dispersion is known as the evolution of evolvability (Kirschner and Gerhart, 1998).

As an example of how the information in the environment enters the genotype, and to quantify the minimal set of genes necessary to keep something alive, Spiegelman conducted some experiments (Kacian et al., 1972). He created environments that were ideal for a Qb virus. Everything the virus needed to survive and replicate was provided (RNA replicase, some free nucleotides and some salts). After 74 generations, the original viral strand of 4,500 nucleotide bases had evolved into a streamlined 218 nucleotide bases. All the extraneous bases normally used as molecular locks or keys to help the virus obtain what it needed atrophied away. The simplest explanation of these results is that in an information-poor environment where there are no challenges, no selection pressure, and no tricks are needed, the information in the bases of the virus is not selected for and diffuses away. Thus, the amount of information in the genotype reflects the amount of information in the environment. This lazy, streamlined, couch potato of a virus became known as Spiegelman's Monster. Thirty years later, Oehlenschlager and Eigen (1997) showed that Spiegelman's Monster could become even shorter, containing only ~50 nucleotides, which provide the binding sites for the RNA replicase (Mareno and Ruiz-Mirazo, 2009). This relationship between environment and genes is generic. If extraterrestrial life exists, then the information in its inheritable molecules will also reflect the information of its environment.

3. The Entropic Paradox: A Low Initial Entropy Seems to Conflict with Observations

There is general agreement that life on Earth (and elsewhere) depends on the non-equilibrium of the universe (Anderson and Stein, 1987; Schneider and Kay, 1994). If stars are shining, if there is any friction, if life of any kind exists in the universe, then the second law of thermodynamics tells us that the entropy of the universe is monotonically increasing. Since the big bang, ~13.7 billion years ago, irreversible dissipative processes have been increasing the entropy of the universe. Thus, the initial entropy had to be much lower than it is today, and in the future, it will be much higher than it is today (Figs. 5 and 6).

The cosmic microwave background (CMB) radiation is almost isotropic. The temperature of this radiation is ~2.7 K in all directions. There is, however, a very low level of anisotropy. The amplitude of the temperature anisotropies are $\Delta T/T \sim 10^{-5}$ (Smoot et al., 1992). This low level of temperature anisotropy after the big bang means that the universe was close to chemical and thermal equilibrium 400,000 years after the big bang. There were no stars or planets, no hurricanes and no luminosity gradients. Density inhomogeneities were comparable to the temperature anisotropies ($\Delta\rho/\rho \sim 10^{-5}$). Thus, according to the standard accounting of entropy (which importantly does not include any term for gravitational entropy), the universe was near equilibrium and therefore near maximum entropy, not minimum entropy. All the entropy terms that we know how to compute were already close to their maximum values. With S at an apparent maximum, in Eq. 1, we would have $F = 0$. That is why in Fig. 5, the point labelled "observed in CMB" is in the upper left. If this were the whole story, the universe would have started near maximum entropy and nothing would have happened: no

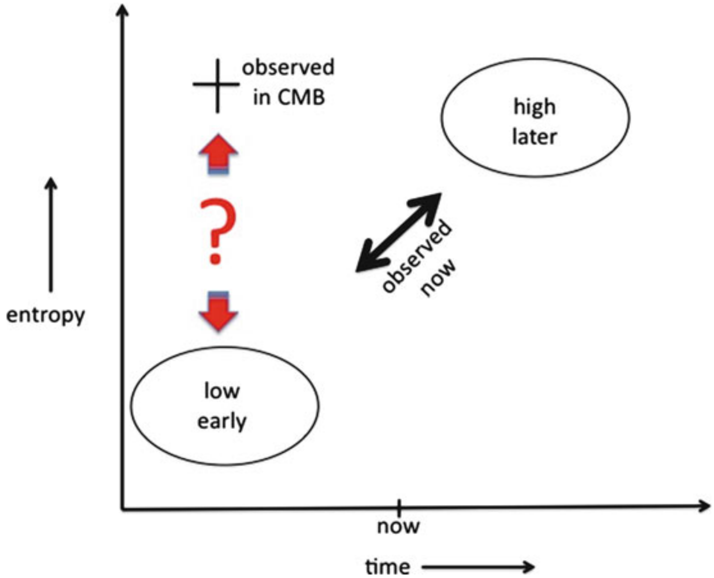

Figure 5. The entropic paradox. The entropy of the universe is increasing. Therefore, in the future it will be higher, and in the past it was lower. A telescope is a time machine; as we look further away, we look into the past. When we look as far away as we can, we see the cosmic microwave background (*CMB*) radiation – the afterglow of the big bang (Smoot et al., 1992). By analysing this radiation, we can see that the early universe was close to thermal, chemical and density equilibrium. That is, the entropy of the universe appears high ~400,000 years after the big bang when the CMB was emitted. Thus, a low initial entropy seems to conflict with CMB observations. There must be some component of the early universe that was at low entropy – so low that it dominated the other entropic terms.

stars, no life, no observers. An observable universe has to start in a low entropic state in order to produce structures like observers.

How can a big bang universe, apparently near equilibrium, have a low entropy? There has to be another entropy term responsible for the low initial entropy, and this term has to dominate the entropy budget of the universe because the other terms were already close to their maximum values. This is an important point. It means that all the chemical, thermal and luminosity gradients that now exist in the universe and support life are ultimately due to a poorly understood and unquantified entropic term that was initially low but which still dominated all the other terms that were close to their maximum values. The missing term is the entropy associated with gravity (cf. next section).

Figure 6 illustrates how entropy, starting at some minimal initial value S_{ini}, has increased over time and is approaching a maximum S_{max}. If $S(t)$ were now at its maximum possible value S_{max}, then the universe would be in equilibrium. Thomson (1852) understood this as a heat death since no heat could be exchanged – everything would be at the same temperature. The universe would be isothermal,

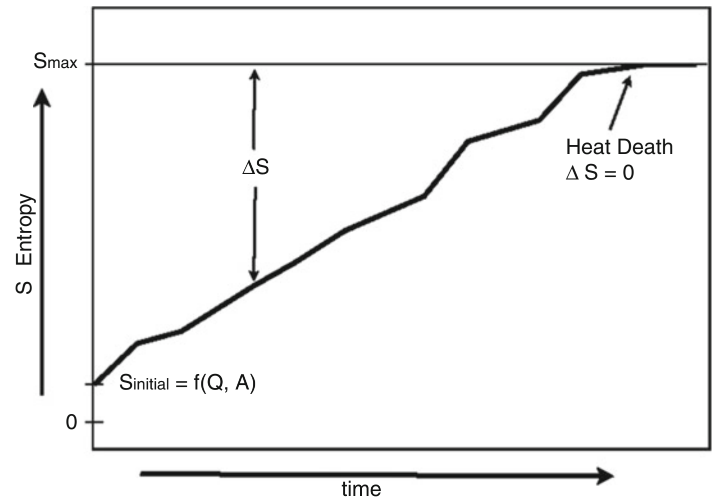

Figure 6. Same as Fig. 5, but constructed to show the entropy gap ΔS (Eq. 4). The second law of thermodynamics tells us that as long as life or any other irreversible dissipative process exists in the universe, the entropy of the universe S will increase. Thus, the entropy of the very early universe had to have some initially low value $S_{initial}$ where "low" means low enough compared to the maximum possible entropy S_{max} so that ΔS is large and can produce and support irreversible processes (including life forms) in the universe. As indicated in the lower left of the figure, the initial entropy is some function of the parameters Q and A which are used to quantify the level of inhomogeneity of the cosmic density distribution (Figure from Lineweaver and Egan, 2008).

isobaric, isodensity – iso-everything. There would be no gradients, no structure, no design and no observers to see all this featurelessness. Equilibrium is a structureless, designless heat death. Since this is not yet the case, there is an entropy gap ΔS between the maximum possible entropy and the actual entropy of the universe,

$$\Delta S(t) = S_{max} - S(t). \tag{4}$$

In Lineweaver and Egan (2008), we showed how the entropy gap is the driver of all irreversible processes.

Since $\Delta F = -T\Delta S$ (Eq. 2), solving Eq. 4 for $\Delta{\sim}S$ would yield an estimate of how much free energy is available in the universe to support life or maintain any far-from-equilibrium dissipative structure. To solve Eq. 4, we need to know $S(t)$ and S_{max}. In Egan and Lineweaver (2010), we reviewed previous estimates of $S(t)$. Based on the latest observations of the mass function of supermassive black holes, we found $S(t)$ to be at least 30 times larger than previous estimates. With this new estimate of $S(t)$, S_{max} is the only important remaining unknown which we address in a paper in preparation (Egan and Lineweaver, 2012). Thus to understand the origin of design in nature, we need to understand the low initial value of the entropy of the universe and the corresponding high initial value of ΔS.

4. Gravitational Entropy

The relationship between entropy and gravity is fundamental and poorly understood. Penrose (1979, 1987, 1989, 2004) has been concerned with the relationship between entropy and gravity for more than three decades (see also Barrow and Tipler, 1986, their section 6.15). Penrose (1979) suggested that a low gravitational entropy was responsible for the initially low value for the entropy of the universe. The low gravitational entropy of the nearly homogeneously distributed matter has, through gravitational collapse, evolved gradients in density, temperature, pressure and chemistry that provide the free energy required by life. As seen in the top panel of Fig. 7, when thermal energy dominates the gravitational binding energy, maximum entropy corresponds to an even distribution of matter. In contrast, when gravitational binding energy dominates, maximum entropy corresponds to collapse into black holes and evaporation, through Hawking radiation into photons. In other words, the low initial entropy of the early universe is explained by the even distribution of matter subject to gravitational force, which

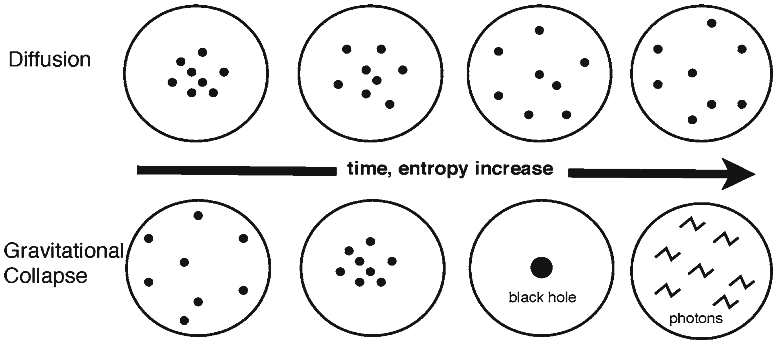

Figure 7. Entropy increases during both diffusion (*top*) and gravitational collapse (*bottom*). It is widely appreciated that non-gravitating systems of particles evolve towards homogeneous temperature and density distributions. The corresponding increase in the volume of momentum-position phase space occupied by the particles represents an increase in entropy. If thermal energy dominates the gravitational binding energy (*top*), then entropy will increase as material diffuses and spreads out over the entire volume (think perfume diffusing in a room). We know how to compute this phase-space entropy (e.g. Binney and Tremaine, 2008). If gravitational binding energy dominates thermal energy (*bottom*), then entropy will increase as some material and angular momentum is expelled to allow other matter to have lower angular momentum and gravitationally collapse into galaxies and stars. We do not know how to compute the entropy associated with gravitational collapse. Stars eventually collapse and/or accrete into black holes, whose entropies we do know how to compute (Bekenstein, 1973; Hawking, 1974). If the temperature of the background photons is lower than the temperature of the black hole, the black hole will evaporate to produce the maximum entropy state – a bath of photons spread out over the entire volume (*last circle in lower panel*). We know how to compute the entropy of a photon bath (e.g. Kolb and Turner, 1990). Thus, the only entropy that cannot be computed is the entropy associated with the gravitational collapse in the *left side* of the *lower panel* (which corresponds to the initial state of matter in the universe) (Figure modified from Lineweaver and Egan, 2008 and Fig. 27.10 of Penrose, 2004).

over time resulted in gravitational collapse that created the energy gradients on which life depends.

Gravitational entropy is fundamental to the evolution of the universe. It is responsible for both the low initial entropy of the universe, and it is the dominant contributor today in the form of the entropy of supermassive black holes. Previous authors have looked at the future of life (Dyson, 1979; Barrow and Tipler, 1986) and the future of astrophysical objects (Adams and Laughlin, 1997). But this fundamental concept is only poorly understood. No consensus about the ultimate future of life and dissipative processes has emerged because the relationship between gravity and entropy has remained confused and unquantified.

How can we quantify the entropy associated with density fluctuations and gravitational collapse? There is no accepted mathematical equation that relates entropy with any of the observable parameters of the initial density perturbations. Initial density perturbations in the universe have been measured (Smoot et al., 1992) as the power spectrum of cosmic microwave temperature fluctuations and as galaxy density fluctuations (e.g. Peacock, 2000). $Q \sim 10^{-5}$ is the observed normalization of the initial fluctuations. We have no mathematical formulation of the relation between the initial entropy of the universe and these measures of deviation from a homogeneous distribution of matter. We have no formula of the form

$$S_{\text{initial, grav}} = f(Q). \tag{5}$$

In addition, observational cosmologists measure and model the growth of large-scale cosmic structure as a power spectrum,

$$P(k,t) = g^2(t)Ak^n, \tag{6}$$

where k is inverse wavelength, n is the spectral index, $g^2(t)$ is the growth factor, and A is the initial normalization shown in the lower left of Fig. 6. Yet we have no formula relating A to the initial entropy or the growth factor to the growth of entropy.

Much has been made of our current inability to unify general relativity and quantum mechanics to arrive at a theory of everything. Although the murky relationship between gravity and entropy may provide key insights into the theory of everything, it has received much less attention. Gravity is almost universally ignored in thermodynamics textbooks. What is known about the relationship between entropy and gravity is similar to what was known about the relationship between energy and heat 200 years ago when the concept of energy conservation in thermodynamics was being developed. It took many decades for the different forms of energy (e.g. potential, kinetic, heat) to be recognized. It seems to be taking even longer to recognize and define the different forms of entropy. The relationship between information entropy (Shannon, 1950) and thermodynamic entropy has been partially clarified (Dewar, 2003; Brissard, 2005). But we still need to clarify and quantify the relationship between gravitational entropy and the other forms of entropy.

5. Inflation, Baryon Non-conservation, and the Homogeneous Distribution of Matter After Reheating, as the Sources of Free Energy

In the last 30 years, to extend the big bang models to earlier times and solve several problems, quantum cosmologists have constructed inflationary scenarios. In these models, the low amplitude initial density fluctuations that have been observed at large scale in the cosmic microwave background radiation, have their origin in irreducible vacuum fluctuations of a false vacuum also known as the inflaton potential (Lineweaver, 2005). Inflation can occur either at the Planck time (10^{-43} s after the big bang) or at the GUT scale (10^{-35} s after the big bang). At the end of inflation is a period called reheating, in which all the energy of the false vacuum is dumped into the universe (Kofman et al., 1994). Matter and anti-matter particles annihilate. However, because of baryon non-conservation and non-equilibrium conditions described by Sakharov (1967), there was a slight excess of baryons over anti-baryons (Dolgov, 1997; Quinn and Nir, 2008). If there were not, all of the matter and anti-matter dumped into the universe at reheating would have annihilated and turned into radiation. Thus, the universe would have started off in a maximum entropy state and stayed that way (Lineweaver and Egan, 2008) – and we would not be here to think about it. However, there was a slight excess of matter over anti-matter, and so the result of reheating in combination with baryon non-conservation was to spread matter more or less homogeneously throughout the universe. Since this corresponds to low gravitational entropy, the universe starts off with a large entropy gap ΔS and lots of free energy, which, on its way to waste heat, can produce and maintain (for a while) all the complex, differentiated structures in the universe.

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Biodata of **Atilla Grandpierre**, author of "***On the Biological Origin of Design in Nature***."

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ON THE BIOLOGICAL ORIGIN OF DESIGN IN NATURE

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1. Design and Teleology

As the Oxford English Dictionary indicates, design is “a mental plan” or a “purpose, aim, intention.” Therefore, design seems to be closely related to teleology. Perhaps the most transparent version of design is the type that is created by man, like the one that is manifest in machines. In a machine, design is manifest in its structure, namely, in its materially manifest “plan” or “working principle,” which controls the function of the machine. Actually, the “working principle” can fulfill the prescribed function only by harnessing the physical laws; that is, machines manifest a dual control—one is exerted by their design, and the other is by the physical laws. Certainly, the design of machines is teleological since machines by their very nature are controlled by human purposes: a car is designed to be suitable for transport, a watch to show the time, etc. What can we know about the nature and origin of the underlying control, the one realized by the physical laws? Physical laws in physics are regarded as the fundamental basis of physical reality. This means that physical laws play an important role in the ontological structure of the universe. Therefore, understanding the origin of control by physical laws requires the exploration of the ontological structure of the universe. Indeed, it is required by the fact that in the concept “design in nature,” the teleological aspects of physical reality play a basic role.

We are interested here in the scientific aspects of natural phenomena or man-made facts that are usually referred with the term “design.” At present, it seems that from the basic natural sciences, physics, biology, and psychology, only physics is a mature and exact science. Regarding the general view that teleology is widely regarded as being “contrary to the whole orientation of theoretical physics” (Yourgrau and Mandelstam, 1960, 154), the scientific study of “design” in nature seems to be problematical in the usual conceptual framework of physics. Yet our aim is to approach this problem with the most exact tools of science. As a preliminary step, let us consider the question: Is there any scientific basis for the general belief in the “design” of the universe?

“The belief in a purposive power functioning throughout the universe (…) is the inevitable consequence of the opinion that minimum principles with their distinctive properties are signposts towards a deeper understanding of nature and not simply alternative formulations of differential equations in mechanics (…)”

(Yourgrau and Mandelstam, 1960, 154). In the last decades, it is more and more recognized that the least action principle plays a central and comprehensive principle of all the fundamental branches of modern physics (Landau and Lifshitz, 2000, 2–3; Feynman et al., 1964, Vol. 2, 19–4; Moore, 1996, 2004; Brown, 2005, x; Taylor, 2003). Actually, it is well known that all the fundamental physical laws (i.e., the laws of classical mechanics, hydrodynamics, electromagnetism, thermodynamics, theory of gravitation, and quantum physics, including quantum field theories and string theory) are derivatives of one and only one deeper-level law—namely, the *least action principle.* It has been remarked (Taylor, 2003) that the least action principle lies at the foundation of contemporary theoretical physics. "The action principle turns out to be universally applicable in physics. All physical theories established since Newton may be formulated in terms of an action. The action formulation is also elegantly concise. The reader should understand that the entire physical world is described by one single action" (Zee, 1986, 109).

Now, if the action principle is so fundamental, and if its property of being a minimal principle is crucial for the deeper understanding of nature, as Yourgrau and Mandelstam claim, then why is it that teleology is regarded as being "contrary to the whole orientation of theoretical physics"? One point is the appearance that "the action is not always the least, like in the case when the particle may move between two points on the ellipse in either of two paths; the energy is the same in both cases, but both paths cannot have the *least* possible action." On that basis, Yourgrau and Mandelstam were quick to conclude: "Hence the teleological approach in exact science can no longer be a controversial issue; it is not only contrary to the whole orientation of theoretical physics, but presupposes that the variational principles themselves have mathematical characteristics which they *de facto* do not possess. It would be almost absurd to imagine a system guided by a principle of purpose in such a manner that sometimes, not always, the action is a minimum" (ibid., 155). Yet we point out that the action principle in its usual form considered by Yourgrau and Mandelstam is restricted to holonomic systems, that is, systems whose geometrical constraints (if any) involve only the coordinates and *not the velocities*; therefore, the conclusion of Yourgrau and Mandelstam does not apply to the case they refer to. After all, it is a simple thing to see that a particle with any given initial velocity cannot start in the opposite direction; therefore, there is no such case "when the particle may move between two points on the ellipse in either of two paths," assumed by Yourgrau and Mandelstam (ibid.). If this is the crucial argument underlying the widespread opinion against teleology in physics, then it does not follow that teleology must be exiled from physics. Therefore, we have to reconsider the problem.

It is true that teleology is not visible at the level of observable phenomena or of physical laws. Indeed, the fundamental differential equations are time symmetric, and so they avoid teleology. Yet at the level of the action principle, teleology is explicitly manifest. In the usual formulation of classical action principles, the initial and final states of the system are fixed and are formulated as follows: Given that the particle begins at position x_1 at time t_1 and ends at position x_2 at time t_2, the physical trajectory that connects these two endpoints is the one that makes the action stationary. "The method does not mean anything unless you consider paths which all begin and end at the same two points. So the deviations have to be zero at each end. With that condition, we have specified our mathematical problem" (Feynman et al., 1964, Vol. 2, 19–4).

For our present purposes, it is enough to realize that teleology (see the entry "teleology" in the Encyclopedia Britannica) is defined as "explanation by reference to some purpose or end." Definitely, the least action principle is based on a relation between some initial and final state; therefore, reference to some end (attention: not necessarily to a purpose)—namely, to a subsequent, final physical state—is already explicitly present. Variational principles are "the contemporary descendants of final cause" (Brown, 2005, x). We can observe that Yourgrau and Mandelstam misinterpreted physical teleology as "purpose" (these are widely different concepts!) and were wrong when claiming that the action principle does not possess teleology. Now, if a kind of teleology is present already in physics, the general opinion that its companion, design, must be "naturalized" (explained in terms of physical forces as effective causes) in order to become scientifically acceptable is also based on a wrong premise.

1.1. MECHANISM AS A WORLDVIEW AND THE RELATED CAUSAL LEVELS OF NATURE

In the last centuries, science as well as philosophy of science has been dominated by the idea of *mechanism*. Apparently, the "mechanism worldview" was formulated as a bedrock of scientific method by Henry Oldenburg, the first secretary of the influential Royal Society, who claimed that all phenomena can be explained exhaustively by the mechanical operation of physicochemical forces (Oldenburg, 1661; Henry, 1988). Physical forces can arise as effects of causes arising at two basic levels: (1) due to interactions between physical objects (which are, of course, mediated by physical laws) and (2) interactions between physical objects directly with the physical laws. A third element is also allowed: (3) "random," "spontaneous," or "acausal" phenomena. Examples are collision of physical objects (1), free fall (2), and radioactive decay or spontaneous emission (3).[1]

Indeed, "almost all physicists who work on fundamental problems" accept that "the laws of physics stand at the base of a rational explanatory chain, in the same way that the axioms of Euclid stand at the base of the logical scheme we call geometry" (Davies, 2004). Yet to take into account the action principle in our explanatory scheme requires an extension of the above-cited, two-leveled

[1] In quantum electrodynamics, radioactive decay as well as spontaneous emission and similar processes are elicited by virtual interactions. In that way, class (3) causes become involved into class (1).

explanatory scheme, and to indicate whether the action principle offers us a deeper understanding of nature or not.

1.2. DESIGN OF THE UNIVERSE AND ITS APPARENTLY NECESSARY NATURALIZATION

A significant attempt of modern physics seeks answers to the origin of physical laws trying to "naturalize" the possible answers (Wheeler, 1994; Hartle, 1991; Davies, 2006), explaining them in terms of "randomness" (Davies, 2011) or by such a highly speculative idea as the "multiverse" (e.g., Hawking and Mlodinow, 2010). Now "a strong motivation for introducing the multiverse concept is to get rid of the need for design, this bid is only partially successful. Like the proverbial bump in the carpet, the popular multiverse models merely shift the problem elsewhere – up a level from universe to multiverse" (Davies, 2011).

We point out that the aim of science, since at least Plato, is to find the minimal number of ultimate principles which are able explain observable phenomena. In this chapter, we carry out this program and explore this road in two steps, obtaining a new, more deeply penetrating and more completely comprehensive explanatory scheme than the one in which "the laws of physics stand at the base of a rational explanatory chain." In our essentially complete explanatory scheme of nature, the first principles of physics, biology, and psychology stand at the base of a rational explanatory chain.

1.3. THE ESSENTIAL SURPLUS OF THE ACTION PRINCIPLE OVER THE PHYSICAL LAWS

It is a widespread opinion that the least action principle is strictly equivalent with the differential equations derivable from it (Yourgrau and Mandelstam, 1960, 156). At variance with this unsubstantiated claim, we point out that the at-present best explanation of the least action principle, Feynman's sum-over-histories approach (Feynman et al., 1964, Vol. 2, 19–4; Feynman and Hibbs, 1965; Brown, 2005), contains definite surplus beyond the differential equations derivable from it. "There is quite a difference in the characteristic of a law which says a certain integral from one place to another is a minimum – which tells something about the whole path – and of a law which says that as you go along, there is a force that makes it accelerate" (Feynman et al., 1964, Vol. 2, 19–8). "It isn't that the particle takes the path of the least action but that it smells all the paths in the neighborhood and chooses the one that has the least action by a method analogous to the one by which light chose the shortest time" (ibid., 19–9). The essential surplus elements are the following: One is the selection of the endpoint corresponding to the least action principle in the given situation, another is exploring all possible paths in the universe[2] (Taylor, 2003), and the third one is the activity of summing up the probability amplitudes of each explored path.

It seems that reality is even more surprising than the presence of an automatic, physical teleology: How is a quantum able to explore all paths in the universe? How is it able to select its endpoint from the gigantic zoo of all possibilities? And how is it able to execute any activity, especially such characteristically intellectual activity like summing up the obtained gigantic amount of information? The answers lead to infinite dimensional Hilbert spaces, where the wave functions exist, and to virtual particles of the quantum vacuum, the physical manifestations of the action principle (Grandpierre, 2007). In our more complete explanatory scheme, a new class of possible physical causes seems to be also available: class (4), containing the first principles, namely, the least action principle of physics, the Bauer principle of biology, and the first principle of psychology.

1.4. SCIENTIFIC EXPLANATION BY FIRST PRINCIPLES: THE ONTOLOGICAL STRUCTURE OF NATURE

We indicate here that the "mechanism" view gives a partial picture of nature, and as such, it can be misleading. We present here the first essentially complete scientific picture of nature, improving what has been considered till now as the "best model of human knowledge," built up on the basis of the Aristotelian model of scientific induction and empiricism by Kepler, Galilei, Bacon, and Newton (Hooker, 1996). Acknowledging about the fundamental significance of the first principle of physics, we allow it to represent a third and ultimate explanatory level of physical reality. Instead of physical laws, as in the explanatory scheme of the mechanism view, we recognize the least action principle as the natural end of any physical explanation since all the fundamental laws arise from it. In our new, broader picture, the universe consists of three fundamental ontological layers: the levels of phenomena, of the laws of nature, and of first principles, representing the surface, depth, and core of nature, respectively.

1.5. ON THE NECESSITY TO INTRODUCE THE BIOLOGICAL PRINCIPLE INTO SCIENCE

It is not generally known that the behavior of biological organisms is governed also by a "first principle," which is the Bauer principle (Bauer, 1967; Grandpierre, 2007).

[2] In the double-slit experiment, Feynman's ideas mean the particles take paths that go through only one slit or only the other; paths that thread through the first slit, back out through the second slit, and then through the first again; paths that visit the restaurant that serves that great curried shrimp, and then circle Jupiter a few times before heading home; and even paths that go across the universe and back. Feynman's formulation has proved more useful than the original one (Hawking and Mlodinow, 2010, 45–46).

The Bauer principle is the first principle of biology since it is mathematically formulated, giving quantitative account of all basic phenomena of life, including metabolism, regeneration, growth and death (Bauer, 1967, 119–132), reproduction (ibid., 133–158), adaptation, and response to stimuli, substantiated by experimentally determined basic relations (ibid., 159–183)—as well as determining the basic law of evolution (ibid., 184–198). The Bauer principle tells that "The living and only the living systems are never in equilibrium; they unceasingly invest work on the debit of their free energy budget against that equilibration which should occur for the given the initial conditions of the system on the basis of the physical and physico-chemical laws" (Bauer, 1967, 51; Grandpierre, 2008a). Its introduction is necessary since no physical theory explains the basic life phenomena as well as biological behavior at the level of the organism, including such observables as the gross behavior of a living bird dropped from a height (Grandpierre, 2007), or the simple action of bending a finger. The complexity of the living organisms, as it is widely acknowledged, is intractably large in the bottom-up approach of physics. A still bigger problem is that this complexity is not static. It changes from time step to time step. Such structural changes are regarded as random in thermodynamics. Yet in biology, these structural changes are not random, but change systematically and consequently and sum up in a complex way which is governed by the Bauer principle. It was shown that this fundamental biological principle can be formulated in terms of physics as the greatest action principle (Grandpierre, 2007). Therefore, biology shows the same explanatory structure as physics: Phenomena can be explained by laws, and all basic biological laws can be derived from the first principle of biology. Based on the newly found fundamental explanatory structure of physics and biology, we postulate that the ontological structure of the universe represents a hierarchical order: Observable phenomena are governed by laws, and laws by first principles. If so, psychology must also have a first principle.

1.6. ON THE NECESSITY TO INTRODUCE THE PSYCHOLOGICAL PRINCIPLE INTO SCIENCE

Let us consider a simple example to shed light on the nature of physical, biological, and psychological causes of natural processes. Why did I jump into the air? Let us approach this problem in two steps. (1) A physicist can claim that I jumped into the air because a physical force had arisen between my foot and the ground. Yet this explanation indicates a further question: Why did these physical forces arise? The answer can be given by the biologist: because biological processes like induction of biocurrents or neural voltage (excitations, action potentials, electric gradients) have been generated and form a system of stimuli extending from the neurons through the nerves to the muscles, making them contract. But then a further question arises: Why did the neurons become excited? The answer a psychologist (a scientist of self-conscious decisions) would likely give is that the neurons were agitated because a willing, self-conscious agent made a decision—in this case, to jump in the air. Apparently, this simple example indicates that the physical explanation by mechanism does not exhaust the problem nor does it exclude the need for a biological or psychological explanation.[3] (2) Of course, the physicist can point out that the generation of the neural voltages and their propagation towards the muscles corresponds to material processes (like ion transfer) which are determined by physical laws. But this claim is only partially true; the generation and coordination of an immense number of elementary biocurrents into a biologically meaningful system of neural processes cannot be *explained* by physics; physical equations do not allow to *predict* them, simply because they serve a *biological* aim, and that aim governs the whole process from its generation to its final manifestations. If so, how are the first neural voltages generated? This is a crucial problem: How can our allegedly immaterial, unobservable decisions elicit material, observable consequences?

1.7. SPONTANEOUS PROCESSES ARE TRIGGERED BY VACUUM FLUCTUATIONS

Answering that crucial problem, we note that we found apparently unnoticed loopholes in physical determinism regarding the significance of spontaneous processes. For example, in spontaneous radioactive decay, it is impossible to determine which atom will be the "next" to decay. By our best present understanding given by quantum field electrodynamics, spontaneous emission and similar processes are due to vacuum fluctuations, that is, virtual interactions (Milonni, 1994), and are not determined at the level of differential equations. In our understanding, such virtual interactions act on a deeper level than the laws of nature, at the generative, principal level of nature, where the action principle acts, and it acts through virtual interactions.

We found that the biological principle, the natural extension of the least action principle, works in a similar manner: by virtual interactions. These virtual interactions represent the interface between "nothing" and "matter"; they can trigger physically spontaneous, that is, physically undetermined, phenomena, such as the spontaneous emission of photons, whereby photons activate biomolecules, triggering spontaneous couplings between endergonic and exergonic processes (Grandpierre, 2008a). Certainly, the biological principle can organize physical

[3]It is easy to observe that the different kinds of explanation of "why did the frog jump into the water?" given by Rose (1997, 10–13, 85–97) missed the target of obtaining a clear and complete picture regarding the nature of causation in nature. At variance of his five types of explanations, all the three causes we indicated here are actual causes, and all of them correspond to a generative principle of reality, which form an essentially complete system of nature.

conditions, the input elements for physical laws, into suitable sequences for successfully fulfilling biological needs and ends. The suitably organized input conditions can lead with the help of physical laws to biologically useful output, like in the case when we bend our little finger. We are led to the insight that biology is the control theory of physics.

1.8. THE EXAMPLE OF THE DROPPED BIRD

Let us illustrate this point with the following example. A live bird dropped from the Pisa tower manifests a characteristically different trajectory than other physical objects dropped from the same location. It is customary to think that the reason for this difference lies in the extreme, intractable complexity of the living bird relative to that of the sorts of objects dropped by Galileo—stones, cannonballs, compacted feathers, etc. Such objects fall uniformly, in "free fall."

Yet the case is different with the complex, living bird. For it can accomplish the feat of regaining its height to the point where it was originally dropped from the Pisa tower, and it can do so without changing its own vital, *specific complexity* during the process. Although all the vital aspects of the bird's complexity prevail, some other aspects of the bird's complexity must change, like the position and shape of its wings or tail. This process unfolds in a highly specific, time-dependent manner. Though the bird is not changing its "vital complexity," it invests work to change the position of its wings and tail in each instant in a way which, instead of being random or sporadic, is continuous and above all consequent. One change comes after another, in such a way that they quickly sum up to an increasing deterioration from the path expected on the basis of physical laws, given the same initial conditions. We must also take into consideration the given initial conditions of the bird: There is a biological principle generating and governing the internally initiated modifications of the physical conditions on which the physical laws exert their influence. The bird harnesses the physical laws and evidently does so with the utmost ease.

The question is: How is this possible? To answer, we are led back to the first principles. How do the first principles exert their physical role? And how does the biological principle act, if all living organisms consist of material particles, and all of these are governed by the physical laws? It seems that "there is simply no 'room at the bottom' for the deployment of additional 'downwardly mobile' forces if the physical system is already causally closed. Thus a typical closed and isolated Newtonian system is already completely determined in its evolution once the initial conditions are specified. To start adding top-down forces would make the system over-determined. This causal straightjacket presupposes the orthodox idealized view of the nature of physical law, in which the dynamical evolution of a physical system is determined by a set of differential equations" (Clayton and Davies, 2006, 46).

1.9. IS THERE A ROOM AT THE BOTTOM?

We indicate that the two-leveled mechanism view of the nature of physical world would not allow "room" even for the activity of the least action principle, which, as we suggest here, is the very bedrock of all fundamental physical laws themselves. In contrast, we point out that there exists an immense realm of physically not completely determined possibilities—for example, spontaneous emission or absorption, fluctuations, instabilities, chaotic phenomena, or spontaneous energy focusing (Martinás and Grandpierre, 2007). We propose that these "holes" in physical determinism allow the generation of significant changes in the observable behavior of living organisms, which are extremely complex systems far from thermodynamic equilibrium. Extreme complexity is necessary in order that the "hole" in physical determinism be sufficiently large, so that spontaneous reactions can dominate the system. Being far from thermodynamic equilibrium is necessary in order for spontaneous processes to lead to macroscopic changes. In suitably organized, complex and far-from-equilibrium systems, an immense number of couplings are possible between quantum states having a large nonequilibrium energy, by spontaneous emission and spontaneous absorption processes between an immense number of spontaneous exergonic (energy-liberating) and endergonic (energy-consuming) reactions; these latter ones require activational energy.

With the help of an illustrative example, biological couplings are like the performance of acrobats in a circus. One *acrobat jumps down onto one end of a seesaw, and another performer standing on the other end of the seesaw gets launched into the air*, and so the otherwise fast equilibration process of the exergonic process that should set up within the individually given initial conditions plus the physical laws will be postponed in the presence of the coupling. In a living organism, an immense number of "acrobats," that is, spontaneous processes triggered by virtual interactions, are coupled by an immense number of "seesaws" (seesaws are simple mechanical machines; living organisms can apply complex nonmechanical "machines" as well) to thermodynamically uphill, biologically useful processes, to realize biological endpoints.

Therefore, although the "bottom-up" view simply regards that biological behavior is "obscured" by the "untractable" complexity of living beings (Vogel and Angermann, 1984, 1), it is possible to shed more light to these depths of complexity. We found that this time-variable complexity is governed by the biological principle.

1.10. THE SOLUTION OF THE MIND-BODY PROBLEM AND THE NATURE OF BIOLOGICAL CAUSES

We note that quantum electrodynamics (QED) is able to give account of the generation of "matter" in quantum processes: QED is able to describe quantitatively the generation and annihilation of particles and antiparticles from the vacuum, which is a "sea" of spontaneously generated virtual particles (e.g., Davies, 1984, 104–106; Milonni, 1994, xv). Therefore, the solution of the mind-body problem—namely, the generation of biocurrents by means of decisions—has a plausible solution: Biocurrents can be generated through virtual particles, through quantum-vacuum interactions (Grandpierre, 1995) that serve biological aims. This is not forbidden but, instead, explicitly allowed by the physical laws. The term "spontaneous" means something not completely determined by physics.

We found not only that biology is an autonomous science having its own first principle but also that this biological principle acts in the same way as the least action principle, namely, through virtual interactions mediating between the biological principle and the material world. Spontaneous processes provide scope for the biological principle to act upon physically not completely determined, spontaneously arising possibilities, so to serve biological ends such as well-being, happiness, survival, as well as routine tasks like biological functions.

1.11. HOLES IN DETERMINISM: CONCRETE EXAMPLES

Now let us offer some more concrete insights into the nature of "holes in determinism." For example, Jacob and Monod (1961) discovered that *there is no chemical necessity about which inducers regulate which genes* (Monod, 1974, 78). "The result—and this is the essential point—is that so far as regulation through allosteric interaction[4] is concerned, everything is possible. An allosteric protein should be seen as a specialized product of molecular "engineering" enabling an interaction, positive or negative, to take place between compounds without chemical affinity, and thereby eventually subordinating any reaction to the intervention of compounds that are chemically foreign and indifferent to this reaction. The way hence in which allosteric interactions work permits a complete freedom in the "choice" of controls (ibid., 78–79). On such a basis, it becomes possible for us to grasp how in a very real sense the organism effectively transcends physical laws—even while obeying them—thus achieving at once the pursuit and fulfillment of its own purpose" (ibid., 81). This means that the *functional* properties of proteins are determined by nonphysical, that is, *physically arbitrary*, processes. It is this arbitrary nature of molecular biology that Monod calls "gratuity."

The basic importance of physically arbitrary processes is frequently acknowledged (e.g., Hunter, 1996; Barbieri, 2002; Yockey, 2005, 6). Maynard Smith (2000) emphasizes the profundity of Monod's idea. He proposes to call the terms for

[4]In biochemistry, allosteric regulation is the regulation of an enzyme or other protein by binding an effector molecule at the protein's allosteric site (i.e., a site other than the protein's active site).

inducers and repressors "symbolic" since there is no physicochemically necessary connection between their form (chemical composition) and meaning (genes switched on and off), just as in semiotics, where there is no necessary connection between the forms of the symbols and their meaning. For example, histidine is coded by the triplet CAC (C stands for cytosine) in the DNA. Maynard Smith calls attention to the fact that *there is no chemical reason* why CAC should not code for glycine instead of histidine. Maynard Smith argues that it is the symbolic nature of molecular biology that makes possible an indefinitely large number of biological forms.

We found that there is a room "at the bottom," and the biological principle can act on matter, making the existence of organismic order, teleology, and design plausible. Now let us evaluate some relations between phenomena, laws, and first principles.

1.12. RELATION BETWEEN PHENOMENA, LAWS, AND FIRST PRINCIPLES

The whole presently observable universe is generated into material existence by deeper-level laws of nature. "Given the laws of physics, the universe can create itself. Or, stated more correctly, the existence of a universe without an external first cause need no longer be regarded as conflicting with the laws of physics.… This makes it seem as if the laws of physics act as the 'ground of being' of the universe. Certainly, as far as most scientists are concerned, the bedrock of reality can be traced back to these laws" (Davies, 1992, 73). Such general views underpin our argument above, which states that all physical phenomena are rooted in laws and, ultimately, in first principles.

Now let us consider the relation between the physical and biological principle. Here we can only indicate that the greatest action principle of biology can fulfill its role only when, after selecting the endpoint according to the greatest action, this endpoint is realized by the least action principle. Illustrating it with an example, a bridge-constructing company wanting to reach the maximum output in a year (corresponding to the greatest action principle), after deciding about the concrete bridges, must build them with the least cost (corresponding to the least action principle), in order that it can reach the maximal output. We can observe that there is a possibility to interpret the relation between the biological and physical one as being such that in a logical sense, the biological principle precedes the physical one. If so, it can be the most ultimate principle of the universe, from which the physical principle arises. "Bauer's dream of theoretical biology was similar to Einstein's goal in physics to create a single equation that encompasses the 'Essence of Nature,' from which all physical phenomena can be derived" (Tokin, 1988). The above argument seems to underpin that Bauer's dream can be realized.

2. Natural Classes of Teleology

2.1. DIFFERENT CLASSES OF NATURAL TELEOLOGY

Teleology has played a significant role in the history of physics (Barrow and Tipler, 1986) and philosophy. Physico-teleology was considered by Leibniz and Kant. *Physical teleology is independent of physical objects*, not only because the endpoint of the trajectory is not selected by the physical object itself, but also because the physical object does not contribute actively to the selection of its trajectory. Indeed, mathematically, different trajectories can have the same endpoints. In biology, the endpoint is characteristically selected by the greatest action principle; therefore, at first sight it may seem that biological teleology is also independent of the system considered. Yet, even if this is true, living organisms actively participate in the realization of their trajectory. First of all, usually the endpoint is not unequivocally determinable, since an immense number of processes occur in a living organism in many timescales simultaneously. Therefore, it is necessary that the living organism itself selects the processes requiring endpoint selection. Moreover, the organism can select the timescale on which the action should be maximized. Additionally, there is a possibility that the organism can select the context of maximization, with respect to its individual or communal life. Moreover, the commitment to the biological principle is not as strict as in physics. While all physical objects must obey the physical laws as secured by the coercive physical forces, there are no such coercive forces in biology. And so living organisms can manifest different degrees in their commitments to the biological principle. At the one end of the scale, they can live their life with almost full vitality; at the other end, they can commit suicide like lemmings. Even in cases when the commitment to the biological principle is strong, as is usually the case, living organisms must contribute to the selection and realization of their trajectory because in biology, many different, biologically possible trajectories can lead to the same endpoint. For example, a bird dropped from a height has many degrees of freedom to select the direction and the form of its trajectory, even when the endpoint is already selected. The biological principle prescribes only one requirement: "Regain your vitality!" All the other parameters, for example, whether the dropped bird selects a trajectory towards north or south, are indifferent for the biological principle and are determined by the organism itself. Therefore, considering biological behavior from different angles, we can find biological teleology either dependent or independent from the considered living organism. This circumstance goes far to explain why viewpoints regarding biological teleology are so controversial.

2.2. OBJECTIONS AGAINST TELEOLOGY

Now let us see somewhat more concretely the objections against teleology based on Mayr (1988, 40), who summed up the traditional objections against teleology in four reasons, namely, (1) teleology is based on vitalism, which is an unverifiable theological or metaphysical doctrine in science; (2) final causation is incompatible with the mechanistic explanation by physical laws; (3) final causation represents a backwards causation; and (4) teleology is a form of mentalism.

2.3. DEFENSE OF TELEOLOGY

Regarding (1), the argument against neovitalism is summed up by Hempel (1966, 72) in the following form. The doctrine of entelechy is not definite enough to permit the derivation of specific implications concerning the phenomena that the theory is to explain. It does not indicate under what circumstances entelechy will go into action and, specifically, in what way it will direct biological processes. This becomes clear when we contrast it with the explanation of the regularities of planetary and lunar motions by means of the Newtonian theory. Notwithstanding, instead of unscientific concepts like "entelechy" or mystic "God," we worked out exact scientific concepts like the greatest action principle, formulated it in mathematical form, and applied it to yet unexplained phenomena (Grandpierre, 2007). Regarding (2), we have shown above that final causation is not only compatible with the mechanistic explanation but is the only means to explain biological behavior at the whole organism level. Regarding (3), already Nagel (1979, 278) pointed out that the agent's wanting a goal acts contemporaneously with the initiation of biological behavior; therefore, it does not represent "backwards causation." Regarding (4), we argue in this chapter that mentalism corresponds to a type of teleology that is not present in physics. This last point requires a suitable classification of teleologies occurring in nature.

2.4. A NEW CLASSIFICATION OF TELEOLOGICAL TYPES BASED ON THE PHYSICAL APPROACH

Appreciating the achievements of physics in becoming the first exact natural science, and aspiring to a similar achievement regarding biology and teleology, we will categorize teleology on the basis of theoretical physics, but, as necessary, expanded by a minimal step allowing endpoint selection corresponding to the greatest action principle. Therefore, as a starting point, we consider the fact that the two fundamental factors governing physical processes are (a) the input (i.e., initial and boundary) conditions and (b) the physical laws. On this exact physical basis, natural behavior can be categorized into the following classes:

(A) The simplest case: The input data are few and fixed, corresponding only to the initial state $t = t_0$. This is the usual case in physical problems. Since the input conditions are simple, the relative complexity of the physical laws is large, and therefore the arising behavior is considered as determined by the physical laws (A1). (A2): The input data can be many and variable in time but simple in a sense that they average out to the arising physical behavior. This is the statistical case.

(B) The input conditions are complex but fixed and do not average out. The simplest case is (B1) in which the input conditions are built in into the physical object in a form of a prefixed scheme, like in the structure of machines or in programs of robots. The behavior of these machines is continuously determined by this basically fixed input (structure, blueprint, or design) plus the physical laws. Even learning robots are always governed by external inputs plus physical laws. Machines are artifacts representing a fixed human purpose to solve a task. Similarly, biological organisms regularly meet in their normal life with the same type of tasks to be solved, such as respiration, digestion, moving the body, etc. These routine biological tasks are solved by functions (B2) of lungs, stomach, muscle, etc. Biological functions significantly modified in their history by natural selection can contribute to the development of adapted features. Biological functions and adapted features represent natural design.

(C) The input conditions to the physical laws are not prefixed but variable in time and contribute to the arising nonphysical behavior. The system continuously changes the internally generated input conditions of the physical laws in order that the output serving varying biological needs can change in a manner corresponding to the greatest action principle. Serving biological needs within changing conditions requires a capability to solve newly arisen problems—in other words, creativity. Type (C1) of biological behavior corresponds to the case when the endpoint of the trajectory is determined by the biological principle. In such cases, the distance of the organism as a whole from thermodynamic equilibrium, which decreases due to the continuously occurring physical processes, is regained, due to biological processes. In the prototype case of a dropped bird, (C1) corresponds to the fact that the bird regains its original height. Teleology of the class (C2) of biological behavior is an aspect of biological behavior which is determined by the autonomous decisions of living organisms. In the case of a dropped living bird, (C2) corresponds to parameters forming other points of the trajectory besides the endpoint, which are determined by the bird itself. Instead of one parameter, the distance of the endpoint of the given process from equilibrium, class (C2) corresponds to other degrees of freedom. The difference between (B2) and (C2) can be illustrated when one considers different aspects of the same biological behavior: the nonautonomous in case (B2) and the autonomous in case (C2). Class (C3) biological behavior corresponds to cases in which the organism can autonomously select, not only the special trajectory corresponding to the given endpoint, but also can contribute to decisions respecting the context and timescales in which its distance from equilibrium can be regained. That is, although the endpoint in a sense is determined by the biological principle (in our example, the dropped bird striving to regain its height above the equilibrium), living beings also have a certain autonomy in selecting the important processes and timescales involved in maximizing distance from equilibrium. Autonomous interpretation of the different contexts (short- and long-term, individual and communal) of the biological principle enables determination of the controllable aspects of autonomous behavior, which in turn can lead to the development of systematically self-conscious behavior to self-conscious goals. The same biological behavior seen in the bending of a finger can be classified as (C2) if it occurs without self-conscious control, "instinctively" or consciously, but it belongs to (C3) if it is a result of a self-conscious decision. In the language of teleology, physical laws refer to "ends," biological ones to "aims," and psychological ones to "goals." The common term comprehending all three together is "telos." Isolated from its system, the heart seems not to have a goal nor an aim, yet as an integrated part of the whole system, it corresponds to an overarching, fundamental biological aim—its function, pumping blood, corresponds to a biological aim of the organism as a whole.

One can see that this new classification is logically systematic and extends to all types of possible behaviors: physical, biological, and psychological. If so, it can be regarded as the first complete scientific classification of behaviors and teleologies. Yet in science, a suitable quantitative measure is inevitable.

2.5. THE MEASURE OF TELEOLOGY: ALGORITHMIC COMPLEXITY

Now let us look for a suitable measure of complexity on the basis of which one can distinguish easily between classes of teleology (A), (B), and (C). Behavior belonging to class (A) is usually regarded as simple, without notable complexity. Yet if we compare the complexity of the physical laws when they are the dominant factors in the governance of behavior, with the complexity of the simple input (i.e., initial conditions), we recognize the complexity of the physical laws can be assessed in terms of algorithmic complexity. Acknowledging the control of physical laws over natural phenomena, we noted above (Sect. 1.3) that in comparison to the mathematical laws, physical laws represent a measure of control, and now we add that this control represents a complexity that can be measured in terms of algorithmic complexity and expressed in measuring units of bits.

In general, the solution of a task requires two kinds of procedures: one leading towards the end step by step, involving a finite number of steps, and one which requires an infinite number of steps. In computable cases, the problem can be formalized and solved in a finite number of steps. The minimum number of steps is a good measure of the complexity of the problem. Indeed, Kolmogorov (1965) and Chaitin (1966) suggested defining the information content of an object as the length of the shortest program computing a representation of it. *The algorithmic complexity* of a mathematically described entity is defined as the length of the shortest program computing a representation of this entity. Since algorithmic complexity is a measure of the complexity of solving a task, which is definitely an end-directed process, teleology is an ineliminable property of algorithmic complexity. Chaitin (1985) determined that the laws of physics have very low information content since their algorithmic complexity can be characterized by a computer program less than a 1,000 characters long. His programs were solved numerically, taking into account Newton's laws, Maxwell's laws, the Schrödinger equation, and Einstein's field equations for curved space-time near a black hole. All were about half a page long—which is amazingly simple. Now we can estimate the complexity of a page as approximately 2×10^3 bits since the average rate of information processing in reading is about 50 bits s^{-1}, and so at a reading rate of 1.5 pages per minute, the information content of a page is about 10^3 bits. Taking a page from Chaitin, we thus found that the algorithmic complexity of physical equations is surprisingly low, being around 10^3 bits.

The distinguishing mark of class (A) is a simple input without complexity; at the same time, physical behavior corresponds to the algorithmic complexity of the physical laws. Class (B) can be characterized by the algorithmic complexity present in the fixed input conditions of machines or adapted features. Remarkably, class (C) has a fundamentally different complexity measure since it corresponds to the solution of continuously surfacing new problems. As a result, the complexity representing class (C) is measured not in bits but in bits s^{-1}. It follows that this kind of complexity can be termed generative complexity (Grandpierre, 2008b). Since generative principles represent a deeper concept than laws of nature, generative complexity represents a deeper level of complexity than algorithmic complexity. We obtained a useful result: The three different kinds of behavior correspond to three different kinds of teleology, design, and complexity, and these can be easily distinguished with the help of quantitative complexity measures.

2.6. COMPARISON OF THE NEW AND OLD CLASSIFICATIONS OF TELEOLOGY

As a test of our new classification of teleologies, we now compare it to that of Mayr (2004). He defined five classes: (1) teleomatic, (2) teleonomic, (3) purposive behavior, (4) adapted features, and (5) cosmic teleology. It is straightforward that Mayr's first teleomatic class (1) corresponds to cases when physical laws determine the output "automatically." His teleonomic class (2) corresponds to cases when the behavior is determined by programs. "All teleonomic behavior is characterized by two components. It is guided by 'a program' and it depends on the existence of some endpoint, goal, or terminus that is 'foreseen' in the program that regulates the behavior or process. This endpoint might be a structure (in development), a physiological function, the attainment of a geographic position (in migration), or a 'consummatory act' in behavior" Mayr (2004, 51). He also includes the behavior of human artifacts like machines into this class. With the recognition that tortoises have short stocky legs adapted for a certain function (namely, climbing, crawling, and walking), and as such represent behavioral programs, we can classify the legs of tortoises as corresponding to our class (B). It is easy to see that physiological functions like the heart pumping blood, migration of birds, or consummatory acts, as well as the complexity of machines, can be characterized by algorithmic complexity, which can be measured in bits, confirming the classification of teleonomic behavior into our class (B).

Mayr's category (3) is that of purposeful behavior. We classified purposeful behavior into class (C) and gave it a somewhat definite meaning. His fourth category "adapted features" is classified into our class (B). This classification is confirmed by the fact that the complexity of adapted features can be characterized by algorithmic complexity and can be measured in bits. Mayr refutes his own fifth class, (5) "cosmic teleology," with the following argument: "Natural selection provides a satisfactory explanation for the course of organic evolution and makes an invoking of supernatural teleological forces unnecessary. The removal of the mentioned four material processes from the formerly so heterogeneous category 'teleological' leaves no residue. This proves the nonexistence of cosmic teleology" (Mayr, 2004, 61). We note that in biology the universal principle of all biological behavior is more basic than the study of some historical aspects of one specific form of life, which is present on Earth. Moreover, instead of supernatural forces, in this chapter, we argued the case for cosmic teleology on the basis that biology has its own autonomous principle which is an exact analogue to the least action principle already established in physics, and so, similarly as the physical principle, it is valid in the whole universe. This means that the biological principle permeates the quantum vacuum, and so it can govern virtual interactions. If so, then the quantum vacuum fulfills the criterion of life, and thus it represents a cosmic life form. Indeed, a detailed consideration of the criteria of life within cosmic conditions (Grandpierre, 2008a) has shown that different cosmic life forms extend to the whole of the universe. This conclusion is confirmed by the simple quantitative fact that algorithmic complexity increases in the universe (e.g., in the protosolar cloud, in solar activity [quantitative study in Grandpierre, 2004, 2008b]) and in the biosphere (Grandpierre, 2008b). Therefore, nature can be characterized by generative complexity corresponding to our class (C). This means that Mayr's "cosmic teleology" actually exists in nature and it belongs to our class (C). This completes our comparison.

2.7. SOME USEFUL EXAMPLES

Now let us look some other useful examples elucidating the differences between these types of natural design.

2.7.1. Homo sapiens from Cosmic Cloud

Definitely, the contraction of the protosolar cloud, from the onset of contraction until the development of the Earth and *Homo sapiens* on it, is conceived today as describable by physical laws. Yet our results indicate (see also Ellis, 2005) that this assumption contradicts the fact that *Homo sapiens* appeared on the Earth, since the physical laws have a fixed and relatively low algorithmic complexity that is measured in bits (10^3 bits), while *Homo sapiens* is a creative being having a much larger algorithmic complexity (10^{15}–10^{17} bits) and having also a generative complexity that is measured in bits s^{-1}.

2.7.2. Physical "Self-organization" Corresponds to Phenomenological Complexity

Physical "self-organizing" processes are frequently regarded as the basis of extremely complex, biological organization (e.g., Kurakin, 2010). Yet we point out that all physical "self-organizing" processes are, at least in comparison to biological organization, *very simple, having a relatively very low algorithmic complexity*. The crucial difference is that physical "self-organizing" processes are governed by the physical laws and manifest characteristically physical behavior. Biological processes differ from physical ones with respect to their governance. Biological organization is governed by the biological principle, while physical self-organization is governed by the physical principle. This is why the latter is much simpler.

2.7.3. Control of Physical Laws: The Dual Control of Organisms

Although physical laws prevail within organisms, their behavior is governed by a dual control, in which the biological control harnesses physics. Mayr (2004, 29) assumes that the dual control is due completely to the genes: "In contrast to purely physical processes, these biological ones are controlled not only by natural laws but also by genetic programs. This duality fully provides a clear demarcation between inanimate and living processes. The dual causality, however, … is perhaps the most important diagnostic characteristic of biology…." We point out that the relation between the two controls, the physical and the biological, is not symmetric, since it is the biological control that determines the characteristically biological behavior, and the physical control is subservient. It is the biological control that regulates the input of physical laws and harnesses the physical laws, not vice versa. The crucial element of transcending physical laws is that virtual interactions are able to induce spontaneous, physically undetermined processes, couple them together in an extremely specific manner, in a way that the biological control can become manifest, observable, as in the trajectory of a living bird.

We add that genetic complexity corresponds to the sequence of the amino acids, and so, it is static and can be measured in bits. Since the solution of new tasks is an inevitable part of life, generation of algorithmic complexity is also inevitable. Generative complexity, measurable in bits/s, is more fundamental than any algorithmic complexity which is already generated. Therefore, if genetic programs play an important part in governing dynamic biological behavior, they must be suitable tools for the activity of the biological principle that continuously generates the algorithmic complexity of biological behavior.

Since man-made control is applied at the input of physical laws, it can harness the physical laws, and it can "govern" the physical laws, similarly to a sailor who changes the inner condition of his ship by trimming its sails in a way to most efficiently harness the physical power of the wind. It is the control of behavior through the control of input of the physical laws that determines the observable gross behavior of organisms, and not the physical laws themselves.

2.7.4. The Mathematical Science of Intentional Behavior

Certainly, modifying systematically and time-variably the input of the physical laws in a way to obtain an outcome corresponding to certain kinds of goals, (C)-type behavior must generate especially complex conditions in order to be manifested. Such especially complex conditions can be made accessible with the help of especially complex internal structures having an especially sensitive and rich set of different internal conditions. The task to produce certain favorable time-dependent output with the help of a suitable selection of time-dependent input variables is investigated in control theory. Control theory is an interdisciplinary branch of engineering and science that deals with the behavior of dynamical systems. The desired output of a system can be generated by the suitable selection of changing input conditions. The description of this type of problem requires the introduction of an extra degree of freedom in problems such as creating the design of a rocket capable of reaching a target governed by a living being (Pontryagin maximum problem). Pontryagin (1978) found that the most important element of such a problem is that the governed system can change all its coordinates at any moment by exerting governmental forces. To take these governmental forces into account, one has to introduce additional degrees of freedom that the living bird has, which the dead bird no longer has. This means that life and its related governmental forces are what elicit the exerted physical forces, and these are the most important elements determining the bird's trajectory. That being the case, one cannot ignore them without missing the main point of the whole problem. In mathematical psychology, the introduction of such an additional variable corresponds to the decisions made by a subject, which can be described with the help of the Reflexive-Intentional Model of the Subject (RIMS, Lefebvre, 2001). The RIMS is a mathematical model that predicts the probabilities of two alternatives a subject will choose, and *it allows us to deduce theoretically the main patterns of animal behavior* in experiments with two alternatives (Lefebvre, 2003).

2.8. THE POWER OF TELEOLOGICAL EXPLANATION

It is usual to assume that teleology is not useful in science. In contrast to this view, we argue here that such an anti-teleological assumption presents a conceptual obstacle to a more complete understanding of nature. The biological principle allows us to introduce biological ends, which in turn represents natural teleology. Such an approach opens up vistas for a new scientific revolution since it makes it possible to understand the behavior of whole organisms in mathematical details, elevating biology to the rank of a quantitative, exact science. At present, the situation is characterized by the following quotation: "Today, by contrast with descriptions of the physical world, the understanding of biological systems is most often represented by natural-language stories codified in natural-language papers and textbooks. This level of understanding is adequate for many purposes (including medicine and agriculture) and is being extended by contemporary biologists with great panache. But insofar as biologists wish to attain deeper understanding (for example, to predict the quantitative behaviour of biological systems), they will need to produce biological knowledge and operate on it in ways that natural language does not allow" (Brent and Bruck, 2006, 416). Our results make observable biological behavior calculable at the level of the organism (Grandpierre, 2007).

3. Is There a Design in Nature?

Contemporary attributions of function recognize two sources of design, one in the intention of agents and one in the action of natural selection (Kitcher, 1999). It is usual to deny the existence of the ontological "design" in the universe. For example, Dawkins (2006, 157–158) acknowledged that (1) one of the greatest challenges to the human intellect, over the centuries, has been to explain how the complex, improbable appearance of design in the universe arises. The apparent design is so spectacular that (2) the natural temptation is to attribute it to actual design itself. In the case of a man-made artifact such as a watch, the designer was an intelligent engineer. It is tempting to apply the same logic to an eye or a wing, a spider or a person. But according to Dawkins, "the temptation is a false one, because the designer hypothesis immediately raises the larger problem of who designed the designer." If so, this "designer problem" raised by Dawkins is solved here. In our picture, the universe is a biologically governed system, governed by the biological principle. Regarding that the first principles exist in all time and space, life is eternal and ultimate. Dawkins continues: "It is obviously no solution to postulate something even more improbable." In contrast, we were able to show that the nature of scientific explanation leads in two steps from phenomena to laws and, ultimately, to the first principles. The existence of these first principles is validated by all our empirical and theoretical knowledge; therefore they are not improbable but, on the contrary, the most probable, actually, universally reliable facts from all science facts. (4) "Darwinian evolution by natural selection offers the greatest, most powerful explanatory scope so far discovered in the biological sciences." Dawkins quickly concludes: "We can now safely say that the illusion of design in living creatures is just that – an illusion."

In contrast, we argued that the theory of Darwin is not fundamental, as it is clear from its contrast with the theoretical biology of Ervin Bauer, which is capable to give the mathematically formulated universal principle of biology. Indeed, Dawkins claims: "We don't yet have an equivalent well-grounded, explanatory model for physics. Some kind of multiverse theory could in principle do for physics the same explanatory work as Darwinism does for biology." In contrast, we think that Dawkins ignores the present situation of biology, as it is shown from reports like the one cited by us above (Brent and Bruck, 2006), indicating the basic fact that at present the only exact science is physics, and biology seems to suffer from missing the knowledge of similarly exact laws and principles. Yet we argued that it is a false opinion since there is an exact formulation of theoretical biology (Bauer, 1967; Grandpierre, 2007). Regarding the multiverse theory, it is based on a superficial understanding of physics, expressing the opinion that physical laws can be awkward. In contrast, we pointed out that the essence of physics is the least action principle, and all physical laws must obey this fundamental principle and should be derived from it. Therefore, a kind of "grand design" of nature—which is revealed here in the three-leveled, "vertical" structure of the universe (phenomena-laws-first principles), plus the "horizontal" structure characterized by physical-biological-psychological behavior—exists, and this ontological structure of the universe is proved by a scientific analysis. The "grand design" we found is represented in the hierarchical architecture of the universe, which has an ontological, explanatory, and causal significance as well.

Hawking and Mlodinow (2010) argued that the material universe can be explained by the M-theory, which predicts that a great many universes were created out of nothing. "Their creation does not require the intervention of some supernatural being or god. Rather, these multiple universes arise naturally from physical law. They are a prediction of science" (ibid., 12). They added: "The fact that we human beings…have been able to come this close to an understanding of the laws governing us and our universe is a great triumph…If the theory is confirmed by observation, it will be the successful conclusion of a search going back more than 3,000 years. We will have found the grand design" (ibid., 102). We point out that the "prediction" of the M-theory, namely, the multiverse theory, does not explain why do the laws of physics take their specific form we observe. Instead, it assumes that since an infinite variety of physical laws exist in the multiverse, therefore every improbable cases have a certain probability, and the specific form of physical laws that are so favorable for life can occur as well with a finite probability. In contrast of this highly speculative and uneconomic assumption, we point out that the existence of physical laws is explained scientifically by the least action principle. Instead of the speculative assumption of the "multiverse," we presented here a scientific explanation for the origin of the physical laws from an exact and already established physical principle: the least action principle.

We found that the universe is permeated by a biological principle capable of controlling the physical principle. This indicates that we are living in a fundamentally living universe, which allows the presence of "design" in nature. Yet we note that the presence of "design" depends sensitively on what we mean on this term. If we mean "order" by the term "design," then already the existence of the laws of physics presents a design in nature. If we mean by "design" teleological behavior in general, we found such teleology present in nature, in biological processes governed by biological aims. If one means by "design in nature" purposeful planning, processes governed by human intentions show their existence.

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CREATIVITY IN NATURE

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1. Introduction

Many people have difficulty with the idea that design can come from nowhere. Some deny it as absurd. The "It's absurd therefore it's impossible" argument against evolution is common today. That was Paley's argument (Paley, 1802), and the argument has been echoed in one form or another for nearly as long as people have thought about the origins of life.

Even many who consider themselves to be scientists have a similar difficulty with the idea that all the incredibly beautiful dancing patterns in nature could have emerged on their own, without a choreographer.

But beautiful patterns emerge all the time, essentially from nowhere. Snowflakes (every one different), landscapes, crystals, sunsets, galaxies, rivers, clay concretions, cloud formations, water waves, and a vast number of other non-living but highly structured systems spontaneously emerge from an unstructured background – or at least from a background that certainly does not contain blueprints for those marvels.

Living things seem to differ dramatically from nonliving natural objects in one crucial respect: they actually *are* built from blueprints. Well, not from blueprints exactly, but certainly from plans. Even though cows and people are constructed from essentially the same components – essentially the same proteins, sugars, lipids, etc. – cows and people differ because their components are assembled in a different arrangement during embryo development. The plan that determines the arrangement is encoded primarily in the DNA present in each fertilized ovum.

So where did that plan come from? Design – the plan – is something we can easily imagine to be evidence of an intelligent, creative Planner.

2. What Is Design?

What do we mean when we say "design?" According to Webster's Dictionary, as a noun, "design" normally means:

(a) A mental plan or scheme for accomplishing a goal
(b) An underlying scheme that governs functioning, developing, or unfolding: pattern and motif <the general design of the epic>

(c) A plan or protocol for carrying out or accomplishing something (as a scientific experiment); *also* the process of preparing this
(d) The arrangement of elements or details in a product or work of art

As a verb, it means:

(a) To create, fashion, execute, or construct according to plan: devise, contrive
(b) To conceive and plan out in the mind <he design*ed* the perfect crime>
(c) To have as a purpose: intend <she design*ed* to excel in her studies>
(d) To devise for a specific function or end <a book design*ed* primarily as a college textbook>
(e) To make a drawing, pattern, or sketch of
(f) To draw the plans for <design a building>

Taking Webster's Dictionary as a guide, it is clear that the ordinary meaning of the word "design" is intimately entangled with the ideas of intention, creativity, mind, and intelligence. When we refer to "design in nature," the phrase itself carries that semantic entanglement, and the arguments begin again. How can there be intention without Someone to do the intending? How can there be a plan without a Planner to create it?

A traditional hard-line scientist, stuck with having to use the phrase, *design in nature*, might try to redefine "design" to mean something really bland, like "any pattern that is potentially interesting to a human being in order to shed the connotations of intention, creativity, mind, and intelligence."

3. Nature as an Information Processor

So how does design emerge in nature? Just for fun, let us see if there is anything other than a God or gods that might exhibit intention, creativity, mind, and intelligence and might be responsible for some of the design we see in nature. First, let us take a look at what we are:

We are each a society of cells.

You are to each of your cells, what a beehive is to its individual bees. You are a complex of interacting, communicating, quasi-autonomous subunits. Most of the components of our cells are present in yeasts and fungi. What distinguishes us – multicellular organisms – from fungi and yeasts is the complex network of communication between our cells, and the range of responses our cells have to signals they receive.

Just as two different brick houses are different because of the arrangement of their bricks rather than the composition of their bricks, different animal species are different because of the arrangement of their cells rather than the composition of their cells. An individual cell from a cow is nearly indistinguishable from a homologous cell in a person. During embryo development, cells exchange mechanical, electrical, and chemical messages that guide cell division, differentiation, and migration. The timing, sequence, location, and content of those messages determine whether a particular embryo develops into a human being or a cow.

Brains are societies of cells that exchange electrical and chemical signals at a pace millions of times faster than the signals passed between cells in a developing embryo. Our thoughts and perceptions are comprised of the timing, sequence, and locations of the signals.

Where else do we find societies of elements, whose essence is in the temporal and spatial patterns of the communication between elements? Ecosystems, certainly, where millions upon millions of species ranging from bacteria to bison, perch to petrels, and hydras to hyacinths, are constantly exchanging information in the form of calls, pheromones, head butts, predation, competition, dances, and genes.

It is especially worth noting that the genomes of all of the organisms on the planet are constantly exchanging genetic information via sexual recombination, retroviral infections, and other mechanisms. It has been estimated recently that 8% of the human genome is derived from retroviral fragments (de Parseval, 2003).

The main driver of evolution is communication, both direct and indirect, between genomes. Genetic information exchanged via sexual reproduction is arguably the largest source of genetic variation driving evolution.

Consider the volume of DNA exchange between organisms. The earth has roughly 5×10^{30} microbes living on it at any given moment, of which, say, one in a hundred million is undergoing some sort of transfer of genetic information with other microbes. The replication cycle of microbes ranges from about 20 min to days or months, so let us say the average replication cycle is 5 days. That means that there are something like 10^{18} genetic signals exchanged per second around the planet. Those signals are not on-off bits like the signals processed by computers; they are chunks of DNA often containing thousands of nucleotides organized into genes and control sequences. So, the genetic signal-processing activity of the earth's biome is on the order of 10^{23} bits per second.

A human brain, or the fastest supercomputer we have built, processes at the very most about a thousand trillion – 10^{15} – bits per second. So, nature processes information at least hundred million times faster than a human brain or a supercomputer.

4. Nature as a Goal-Driven System

All that signal exchange does nothing useful unless it is organized. Is nature's processing power organized? You bet! All of it is aimed at adaptation – generating alternative phenotypes and testing them through natural selection.

All of evolution is guided by natural selection. Natural selection is not really "survival of the fittest"; it is all about continuity of lines of descent. If a line of descent stops, natural selection has selected against the genomes represented by the last individuals in that line of descent. It is difficult to define a really good measure of evolutionary success because if circumstances were right, a nearly extinct population could produce an explosion of new species, some of which could outlast all of their competitors. However, differential replication rates within an interbreeding population or between species that compete for the same resources provide a useful if inexact measure of evolutionary dynamics in any relatively short time interval. All of the hundred million supercomputers' worth of genetic information exchange going on in nature is, one way or another, involved in creating new genetic combinations resulting in new phenotypes, which are then tested by natural selection.

I like to think of *intelligence* as information processing directed toward a goal. It does not have to be a specific long-term goal; it can just as well be a goal, like surviving another day, or even a cluster of goals like staying well-fed, mating whenever possible, avoiding pain, and so on.

An individual social insect like an ant, bee, or termite, responding to chemical signals and other cues by picking small objects up or setting them down, turning or continuing, laying down new chemical signals, regurgitating, etc., is not necessarily intelligent by this definition. But a termite *colony* is intelligent by this definition. Through the interactions between its members, it responds intelligently to threats and opportunities. Its goal (whether or not it has a *mind* to conceive of the goal) is to continue its line of descent.

So, it is not unreasonable to think of nature as an intelligent system with the processing power of a hundred million supercomputers and the goal of exploring the universe of genetically defined phenotypes and ecosystems and testing them via natural selection.

5. Creativity in Nature

When we mention *design*, we generally think in terms of some mix of artistic and engineering creativity. According to Webster's Dictionary, *to create* is to produce through imaginative skill, or to bring into existence through a course of action. A *design* is usually thought of as the product of goal-directed intelligent, creative effort.

So, when we mention evolution (canonically, an undirected, mindless process) and "*design* (a directed, creative, intelligent process) *in nature*" in the same breath, we have already set an argument in motion. Or have we?

Let us consider what we mean by creativity. For the moment, we will set aside the unarguably creative process undergone by an inventor or artist and focus instead on processes that *are not* unarguably creative.

One of my favorite stories about creativity was first told 30 or 40 years ago. I read in a newspaper that a workman had found a scrap of sheet metal that vaguely resembled a cat. He and his coworkers conspired to enter it into an art competition, and it won a prize. When it was revealed that the scrap metal cat was the product of chance rather than intentional effort, a debate ensued. Did the piece deserve a prize? Was it art? Who was the artist? The judges defused the debate by declaring in essence that art is in the eye of the beholder, and it was the workmen who first recognized the artistic value of the scrap metal. By declaring it to be a cat, the workmen committed an act of artistic creation.

I like that story because, in a way, it contradicts a statement my art teacher in middle school repeated often: "Art is not a mistake!" That statement, boiled down, is equivalent to the creationist's axiom that design requires intent.

On one hand, the scrap metal cat was a mistake: a chance occurrence of unrelated cuts in a sheet of steel, followed by a construction worker's finding the discarded chunk and (somewhat by chance) seeing it as resembling a cat. On the other hand, it was not a mistake at all. The construction worker evidently had an artist's eye. He and his eye turned the random scrap metal pattern into an artistic representation of a cat simply by calling it that.

It is a mistake to think that randomness does not play a large role in every act of creativity. If something is new, it stems from a kernel of randomness surrounded by a matrix of preexisting structure. An artist who deliberately splashes paint on a series of canvases, then keeps only those that meet his artistic criteria, provides the preexisting structure (his criteria) and harnesses the novelty inherent in his random splashing. A sculptor who adapts his vision to uncontrollable (random) nonuniformities as they are revealed in a block of stone is harnessing the random variation in the stone's properties while providing the structure of his artistic criteria.

But what of pure imagination and inspiration? What of the artist who constructs a detailed image in his mind before committing it to paint on canvas? What of the composer who imagines a whole symphony before writing a single note on paper? What role, if any, does randomness play in is kind of creativity?

Randomness plays exactly the same role in mental creativity as it does in the paint-splashing artist's creativity. Randomness is exploration.

I cannot prove it, of course, because mental creativity has not been dissected down to the level of detail that would reveal a source of the little kernels of novelty that grow into a full-blown concerto or a painting in an artist's mind. But I can demonstrate without a doubt that a computer using randomness in a matrix of structure can generate inventions *de novo* that the US Patent Office would recognize as novel.

This, too, is one of my favorite stories. Twenty years ago, I designed my own version of a *genetic algorithm or "GA,"* a computer program that mimics Darwinian evolution to solve complex problems. A GA represents potential solutions to a problem as strings of numbers, with each number determining some aspect of the solution. For example, the problem might be to design an improved forklift mechanism, and the individual numbers might represent possible lengths of the components, sizes of gears, diameters and lengths of hydraulic cylinders, and so on. The task of the GA could to be find a compact mechanism that has maximal lifting force while keeping all the mechanical stresses within practical limits.

In order to search for optimal designs, the GA first creates a population of random designs, each represented simply by a string of randomly selected numbers. The designs are compared by calculating their performance. A new generation of designs is created by recombining designs. This is done by selecting a pair of strings, cutting each member of the pair at the same random place, and switching segments between the two members. Better-performing designs are selected more frequently than worse-performing designs for this pairing operation, so higher-performing designs contribute more information to the next generation than worse-performing designs. A few random mutations – shifts in the values of the numbers – are thrown in for good measure. The result of all this is that the designs represented by the members of the population get better and better. A GA is not guaranteed to find the best possible design, but it is very likely to find an excellent design.

In my case, the problem was to design a good lens system with four elements or less that could fit into a 10-in. cube. I handed the task to my GA and let it run overnight. It is important to note that the only information I provided to the genetic algorithm was the goal and a method to determine the quality of a solution. The goal was to find four-element lens systems shorter than 10 in. that form the highest quality image. I gave the genetic algorithm no limitations or advice at all about lens positions, diameters, or powers.

By the next morning, my genetic algorithm had reinvented most of the four-element lens systems ever invented and patented by human inventors. When a human scientist designs a lens system, we consider it to be a creative act. All the connotations of “design” and “creativity” relating to intention and intelligence are clearly appropriate. Is there really any reason the same product (a lens system design) should not be called a design, regardless of whether it was brought into existence by a man or a machine? Is there really any reason the same process should not be called intelligent or creative regardless of whether it was performed by a man or a machine? I think not.

Nature has the original genetic algorithm, which we call *Darwinian evolution*. It operates on strings of nucleotides rather than strings of numbers. Nature’s genetic algorithm is far more powerful than my poor imitation. My GA used a population of 20. Nature’s populations range from a handful to billions. My GA can only estimate the performance of a design; nature calculates the performance of each design exactly. My GA ran on a computer whose capacity was limited to testing about one design per second. Nature’s GA runs in the real world, testing something on the order of 10^{23} designs per second.

By any reasonable and nonchauvinistic standard, nature has the means to create designs ten thousand billion billion times faster or more intricate than we can. Nature certainly has the capacity to be creative.

6. A Natural Mind

To me, a mind is simply the hierarchy of goals that drive an intelligent system.[1] That is not very far from the common meaning of "mind." Your hierarchy of goals, working in the context of experience and available information, determines the way you feel and the way you act. To "change your mind" is to change your immediate or distant goals. But in its common usage, "mind" hints at something supernatural. We tend to deny the possibility that a computer can have a mind, for example. However, if we define mind as the hierarchy of goals that drive an intelligent system, we can step aside from any supernatural connotations.

Does nature have a hierarchy of goals? Does it have any goals at all? I do not mean teleological end goals imposed by a supernatural entity. I mean goals of the sort that human beings have, like filling an empty belly, finding a mate, or storing food for the winter.

Yes, nature has a hierarchy of goals. We see squirrels, bees, ants, and birds storing food for the winter, at the cost of expending extra effort in the summer and fall. Birds build nests in advance so that they will have a safe place to lay eggs and incubate them. Geese and ducks migrate thousands of miles twice a year to raise their families safely.

Nature also "plans ahead" in ways less apparent than migrations, nest building, and food storage. It is no accident that the mechanisms of reproduction are structured at the subcellular level to maximize random genetic variation while ensuring that a majority of the variations produce viable individuals. Similarly, it is no accident that we are born with the ability to heal when wounded and mount an immune defense when bacteria invade. Even if we were never wounded or exposed to bacteria, we would still have those abilities in reserve.

If I programmed a robot to take note of the locations of electrical outlets it sees, so that when its batteries ran low it could scurry to the nearest outlet, there would obviously be some sort of intention at work. Most people would attribute the intention to me, though – the robot's programmer. *But what if nobody wrote the robot's program*?

A genetic algorithm can design a computer program as easily as it can design a lens system. A computer program is a string of 1 and 0 s, just like the 1 and 0 s in a computer's representation of a fork lift mechanism or a lens system. So, a GA could be given the task of designing a computer program that directs a robot to remember locations of electrical outlets in case of future need. And it would succeed.

The forward-looking behaviors observable in nature are programs encoded in DNA. They are programs that were designed by nature's GA.

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[1]This is similar to Csikszentmihalyi's definition of self: "The self represents the hierarchy of goals that we have built up, bit by bit, over the years" (Csikszentmihalyi, 1990; Csíkszentmihályi and Csikszentmihalyi, 1988).

It is easy to explain these forward-looking behaviors and abilities in Darwinian terms. After all, practically every one of our millions of ancestors was wounded or sick at some point in life before having the opportunity to produce offspring, so nature has selected against organisms without appropriate defenses. To an evolutionary theorist, it is very straightforward – all that remains is to find a plausible way for those defenses and behavioral programs to have emerged through a series of acceptably small, usually beneficial, steps that involve random variation and fitness-based natural selection.

But I would like to offer an alternative suggestion.

I would like to suggest that, through the usual process of Darwinian evolution, genetic machinery *per se* has become (in effect) a forward-looking adaptive system. A shelf full of books could be written to lay the foundation for arguments in favor of this idea, but since there is not room here for that, I will offer a few plausibility arguments instead.

In a changing environment, there should be a definite selective advantage to organisms whose reproductive machinery is structured at the cellular level in a way that makes them more likely to produce offspring that have genomes as varied as possible while having a high likelihood of being viable.

In effect, all eukaryotic genomes are structured this way because the arrangement of genes in multiple chromosomes ensures that *genetic modules having proven fitness* are combined in novel ways during practically every instance of sexual reproduction. In human reproduction, for example, with our 23 chromosome pairs, each new individual is formed from one of 4^{23} (over 70 trillion) possible combinations of chromosomes – practically every one of which is sure to be viable. Crossover (random exchange of DNA segments between homologous chromosomes) is another mechanism that creates new genetic. The number of possible crossovers between two parent genomes is vastly larger than the number of possible chromosome combinations, but the vast majority of combinations resulting from crossover will be viable.

In other words, DNA and its associated molecular machinery is organized in such a way that it evolves rapidly in response to changing selective pressures. I would suggest that it is organized that way because it *needs* to be organized that way. Natural selection works against organisms that cannot evolve quickly enough to keep up with environmental change. More importantly though, natural selection works against organisms lacking the ability to compete effectively with those that evolve quickly – because an organism's competitors are, themselves, powerful agents of natural selection.

So, evolution has not only given life its existence, but has also given life both the means and an imperative to evolve rapidly. The means to evolve rapidly are hardwired into the very structure of our cells at the genetic level. The imperative to evolve is inherent in the nature of natural selection.

Without any idea of end goals, nature is driven to proceed as quickly as possible, on all fronts, in all accessible directions. The drive is encoded in the combination of evolved DNA structures and in the very process of evolution.

To nature, any inheritable change that sustains a line of descent is progress. Like water, whose gravitational imperative is to flow downhill rather than to reach the ocean *per se*, nature's evolutionary imperative is to continue lines of descent rather than to develop any specific, predetermined forms. However, the same could be said of termites, each of which responds only to signals it comes directly in contact with. Any individual termite acts only locally, with no understanding that its acts contribute to long-range processes such as building a 4-m-high air-conditioned nest.

Nature does have a mind, if mind is the hierarchy of goals that drive an intelligent system.

7. Emergence of Design

Now, we can return to the question of how design emerges in nature.

It is clear that the set of local rules governing acts of individual termites causes a whole termite colony to act in concert to construct a nest. It is clear that the set of local rules governing the behaviors of individual cells in a developing human embryo act in concert to cause the collection of cells to construct a baby. In a very real sense, the termites' behavioral rules or the embryonic cells' behavioral rules have goals built into them: they exist for a purpose. Evolution is a learning process, and it has learned that termite colonies composed of individual termites whose genes encode rules that result in collective nest-building behavior are more likely to have unbroken lines of descent. Similarly, evolution has learned that colonies composed of human cells whose genes encode rules that result in collective baby building are more likely to have unbroken lines of descent.

From that perspective, there seems to be a fundamental difference between the rules governing behavior of living organisms like termites and human cells and the rules governing behavior of water molecules. That is, the rules governing insect behavior and embryonic cell behavior have been shaped by evolution, and the rules governing water molecules have not. Oceans, lakes, raindrops, and rivers are natural consequences of water molecule physics, but are not the *purpose* of the rules.

We have a pretty good grasp of the rules that govern evolution at the molecular, cellular, species, group, and ecological levels. In scientific circles, it is effectively taboo to speculate on the purpose of those rules because we usually think of "purpose" as connoting intention, which we habitually attribute only to human beings or at most only to "higher" animals. However, I think it is worth asking, "To what extent have the rules that govern evolution been constructed by evolution?"

The answer can only be that very little of what governs evolution *is not* itself a product of evolution! Meiosis and mitosis are evolved processes. Predator/prey interactions are evolved processes. Mate selection behaviors are evolved processes. Competition for resources is a process dependent on evolved organisms and evolved behaviors.

Evolution may not proceed toward a preordained *end* goal, but it certainly is composed of processes that include at least "immediate" goals like nest building, baby building, homeostasis, and maintaining the ability to adapt.

In a separate book, I have proposed a new definition for *design*. The definition is constructed to shed the supernatural aspects of the ordinary definition.

> Design is the property common to useful structures discovered during intelligent exploration guided by a hierarchy of goals.

By "useful structure," I mean a structure that makes a task easier or more efficient; by "intelligent exploration," I mean exploration guided by a complex information processing system; and by "goals," I mean rule sets that have evolved through variation and selection.

Practically anything we think of as a design fits that definition: music, architecture, paintings, computers, and contracts. Even the scrap metal cat was "discovered" by an alert workman and useful for goals conceived by the workman and his coworkers.

More to the point, practically everything we find in nature fits that definition. Nature is undeniably a complex information processing system. It is replete with goals. Practically every feature of living organisms that persists for a significant number of generations is useful to the propagation of a line of descent; if it were not, it would be subject to deletion by natural selection.

Let us briefly consider two examples of design in nature, through the lens of this definition: the shape of a cutthroat trout and the structure of a fly's eye.

The usefulness of a trout's shape to the trout is obvious: it allows the trout to move through the water with minimal turbulence and propel itself with minimal expenditure of energy. The shape emerges from the collective action of individual embryonic trout cells, each of which acts according to the same set of rules in response to local circumstances. The rules evolved over some billions of years as a result of highly structured genetic exploration constrained by natural selection and the laws of physics.

A fly's eye is useful to the fly. It helps the fly detect and locate food sources, predators, and potential mates. Its shape emerges through the collective action of fly embryonic cells, individually following rules written into the cells' DNA over billions of years via variation and selection performed by a genetic algorithm operating in a parallel processor enormously more powerful than anything built by people.

We look at fish, flies, flowers, and firs, and we see design. We think we see signs of intelligence, creativity, and purpose. Of course we do!

Nature *is* intelligent: it processes gigantic amounts of information in a highly complex, highly structured way. Nature *is* creative: it has structured itself into an enormously powerful engine of innovation. Nature *is* purposeful: it has evolved numerous mechanisms and behaviors to help it pursue its goals of adapting to selective pressure and maintaining its myriads of lines of descent.

Nature's intelligence, creativity, and purpose are not illusions, but neither are they supernatural.

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