Natural evolution, human creativity and engineering design in the context of paradigms of modern physics

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Abstract

It is often said that the prime mechanism of the Darwinian evolution is a combination of random mutations and subsequent survival of the fittest. This article discusses several evolutionary lines, such as Cosmic evolution, Darwinian biological Evolution on our planet, common Engineering Design as it evolves over the millennia of human civilization, some fundamental questions on nature of reality and meaning, and artificial computer-aided creativity.
Keywords: cosmic evolution, biological evolution, complexity emergence, ascendance, ergodicity, creativity, engineering design, randomness, quantum physics, digital strings, set theory, chaos theory.

1 Introduction

Engineering Design (ED) in a narrow sense is, for the most part, a goal-oriented activity targeted for a particular application or a class of applications. Emphasis on inter-disciplinary connections and "Renaissance" vision is becoming common trend in engineering education [1,2]. In a broader philosophical context Interdiciplinarity may be seen as just another facet of inner inter-connectivity of the natural world. We notice that several paradigms of modern science, such as Quantum Physics, Thermodynamics and Statistical Physics, Chaos Theory and Theory of Infinite Sets, can provide a connected synergetic framework to encompass key aspects of these evolutionary lines. Here we discuss several, often overlooked, interdisciplinary connections relevant to natural and engineering design. It should be noted that modern Web search engines using key terms and/or names of key authors make traditional reference system on

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published sources almost redundant and obsolete. This fact allows us to minimize formal literature references in this article.

2 Physics as a foundation of natural design

Physics, by its very essence ("nature" in Greek) is often called The Queen of Sciences. This is not to claim some "professional arrogance" (which, to some degree, exists in almost any profession), but simply reflects the fact that it indeed incorporates in itself as "sub-sets" almost all natural sciences (chemistry, biology, etc) and, by extension, almost all engineering. Regardless of terminology, physics is the foundation of almost everything in the material world.

2.1 Physics as a universal paradigm

Major strength of physics is that it bases its conclusions and theories on observations and targeted experiments. However, all models (and theories) operate within a limited set of parameters and assumptions and, therefore, we always have to address issues of their inner incompleteness and limitations, using, so to say, a careful conceptual bracketing. This is often referred as a premise that a new stage of progress calls for a new "Paradigm Shift" as was amply argued by Thomas Kuhn and many of his followers.

2.2 Phenomena, concepts and laws

In physics we make a distinction between objects, phenomena, concepts and laws. All these are, of course, human terms. But differences between them are more than a mere linguistics.

Objects (or "things") are the easiest of all. Most of what we see around (by unaided eyes or with instruments) can classify as objects.

Phenomena (sometimes called "effects", although both terms are not entirely equivalent) are, for example, gravitational attraction between masses, electrical discharges (e.g., lightning), thermal conductivity, thermal expansion, freezing and melting, etc.

Concepts generally refer to mental constructs we use to qualify and quantify the world around us. Mass, energy, temperature, pressure – are all examples of concepts. Again, there might be some subtlety and uncertainty in what are the concepts. The demarcation between physics and metaphysics (that is, according Aristotle, is "what goes after physics") may become fuzzy. Is "time" a concept? Is electromagnetic field (or field of gravity) an "object" or a "concept"? Here probably we will find a diversity of opinions.

And, finally, *physical laws*. Laws of Newtonian (classical) mechanics, variational principles, laws of electromagnetism (Maxwell's equations), laws of Thermodynamics, laws of Quantum Physics (Schrodinger's equation), etc. These are mental constructs which, nonetheless, encompass a broad range of phenomena and have ample experimental confirmation.

2.3 Energy and information

Energy is one of the prime concepts of physics. Virtually nothing can be measured, and least so interpreted, in physics without using this concept. And yet, in recent years, another concept has entered in some kind of a "competition" with energy for the first place in importance. The concept of *information*. Information is, of course, an old concept and its links to physics can be traced from informational interpretation of entropy by Ludwig Boltzmann. But lately, due to Claude Shannon and many others, this concept attained the full right as a physical (not just mathematical) concept. Recent developments in Quantum Computing [3, 4] just add to that. Furthermore, according to MIT physicist Seth Lloyd, all physical systems can be thought of as registering and processing information [3]. This statement applies from microscales (e.g., sub-nuclear) to cosmic scales and processes of the magnitude of the Big Bang (BB).

2.4 Randomness: classical and quantum

Randomness, like freedom, is more a metaphysical (perhaps, even philosophical) category than a physical one. In factual terms, of course, there are many phenomena and processes which we quite justifiably call random. Debates about the nature of randomness go even into the depths of fundamental mathematics – an example is the so-called "*Omega Number*" introduced by Gregory Chaitin [5].

2.5 Variational principles

Variational principles refer to several mathematical laws formulated mostly in 18th century. In 17th century Pierre de Fermat introduced what later became know as Fermat Principle. Known also as the Principle of Least Time, it states that a ray of light, when it propagates from point A to point B in an optically non-uniform medium (with changing index of refraction), takes the path which can be traversed in the least time. Pierre Maupertuis introduced Least Action Principle in mechanics. Later on, somewhat different formulations of the same idea were offered by William Hamilton and Joseph Lagrange. In quantum physics the energy operator is called traditionally "Hamiltonian" since it represents a quantum analogue of the function introduced by Hamilton.

In modern Theory of Chaos and Complexity Theory teleological aspects are often referred to in a context of the notion of "attractor" – some dynamical state of phase trajectory to which the system is attracted (term "teleology" - not to be confused with "theology" - means any goal-driven activity or dynamics). There are many reflections on that in the evolutionary context (e.g., Stuart Kauffman). If purposefulness (Aristotelean C*ausa Finalis*) is a foundation of ED (all engineering artifacts are created for a specific purpose), why not search for the same (or similar) principles in the workings of Nature, in Natural Design? Thus, variational principles provide a yet another platform for interdisciplinary integration in the spirit of Renaissance people like Leonardo Da Vinci.

3 Physics and Mathematics: who needs whom?

In a spite of some professional tensions, Mathematics and Physics have long history of most fruitful cooperation. Physicist Eugine Wigner wrote about the “amazing effectiveness of mathematics as applied to the physical world” [6]. This notion constantly reiterates itself throughout the history of science.

3.1 Physics and mathematics: perfect couple with occasional arguments

What is often called an “Ideal Platonic World of Numbers and Forms” (mathematics) can indeed be a foundation of the material (physical) world. And that is far more than just a reluctant marriage of convenience. Such issues as distribution of Prime Numbers, infinite digital strings of fundamental constants of mathematics (e.g., pi = 3.14159…, e = 2.71828…, etc) and similar numerological aspects of the physical world (e.g., fine structure constant [approx 1/137], or mass ratios of elementary particles [1836 for proton to electron], etc) are constantly remain in the mind of many people in their attempts to contemplate how Nature arrives to its intricate designs.

3.2 Set theory and infinity

Theory of Infinite Sets, creation of Georg Cantor, is one of the most powerful and far-reaching achievements in mathematics. Infinity, including infinititude of possible forms, leads (in principle) to an unlimited range of options for Natural Design [3, 5, 7, 8]. It can be said that the mainstream science became more “infinity friendly” over the last few decades.

4 Complexity emergence in engineering design

Complexity emergence is among the most controversial issues in the whole area of Evolution and Natural Design. The key puzzle here is how such complicated and self-regulating systems as living beings can arise from the primordial chaotic mess of disorganized particles generated during BB. On the other end, biochemist Donald Forsdyke notices that the design by evolution is often very inefficient (“we all make mistakes”). One of his examples is a “wrong” wiring of the larynx nerve in giraffes (it is much longer than is needed and hence reduces the speed of hearing predators). In terms of morphogenesis (emergence of new forms), natural evolution shows similarity with a pattern of stress-strain relationships in ED when new inventions often appear as a result of a sufficient pressure of external forces (like consumer demand).

4.1 Mathematical foundations of complexity

The idea that Number is the foundation of everything goes back to Pythagoras (6th century BC), if not earlier. Its evolution over the millennia and non-ceasing interest to it from many quarters of science and philosophy points to its inner strength. Recent developments in mathematics of pattern formation (chaos, bifurcation cascades, Mandelbrot-like sets, etc) gave a new breadth to this idea. It can be said that Natural Design is both analogous and digital. Platonic Libraries of Patterns are waiting to be applied to the mathematical theory of Natural Design as well as human activities such as computerized creativity and quantum computing [4]. In fact, taking into account the fact that we are part of the Nature in a grand sense, the boundary between "strictly natural" creativity (Design by Nature) and human creativity (including computer-supported) becomes fuzzy and arbitrary. Even such basic construct as Periodical Table of Elements is saturated with design.

4.2 Ergodicity and ascendance

These are two principles which at first glance may appear unrelated, but at a more careful view show strong conceptual interconnectedness. The first one is about availability of "construction material" for evolutionary and engineering design, the second one refers to the reformulation of the complexity emergence dynamics.

4.2.1 Ergodicity principle

In Statistical Physics the notion of *Ergodicity* means that the phase trajectory of most systems sooner or later will pass arbitrary close to any point of the phase space which lies on the (multidimensional) isoenergetic surface. In the context of Natural Design, this principle points to a resourcefulness of nature in trying an enormous diversity of evolutionary paths and design combination (trial and error routes).

Physical processes of Spontaneous Symmetry Breaking (SSB) are, in fact, examples of structures emerging from chaos (order from disorder). It is worth noticing that in physics sometime a very weak factor can trigger SSB, e.g., weak interaction works as SSB mechanism in particle physics in the theory of beta-decay. Also, symmetry in Nature is often "hidden" and requires special conditions to show up. For example, the existence of anti-matter and particle-antiparticle symmetry (e.g., electrons and positrons) can only be revealed at experiments using high energy factors (accelerators or gamma photons).

Another natural example for that, yet awaiting its massive applications in ED, is Self-Organized Criticality, concept introduced by Per Bak. It points to a preferential evolution of multi-parametric systems towards states at the interface of chaos and order. Emergence of structures from chaos is a natural analogue (and perhaps, ultimate foundation) of artificially created sources of information design engines, such as Dada engine [4]. Such methods (at times used in ED) as brainstorming (which inevitably has some elements of randomness in it) provide an advantage of enormous number of possible combinations. At a tower exponential level [7], use of decimal (or binary) information-carrying strings cut off from infinite decompositions of transcendental numbers, such as pi, potentially supplies Nature with tools for designing an almost infinite plethora of its amazing structures. In terms "Library of Babel" metaphor of Jorge Luis Borges [4, 7, 8], the latter is tantamount to picking up the "correct" book from the shelf of such a Library.

4.2.2 Ascendance principle

Dynamical key to the complexity emergence is often sought in the SSB. Generally, thermodynamical system "by itself" evolve from order to disorder. Systems asymptotically tend towards the state of maximal entropy (Second Law of Thermodynamics). Such states has maximal randomness. Biological evolution exhibits the opposite trend. The processes here are *anti*-entropic, in seeming violation of the Second Law. How it can happen? One explanation of that may invoke above mentioned mechanism of ergodicity.

4.2.3 Ascendance-related physical effects

By ascendance we mean evolution from simple (disorganized) elementary units to complicated structured, and often self-regulated, systems. Naturally and artificially designed systems (ED) are, as a rule, goal-oriented entities. This means that at the core of their functioning (and hence design) there is some teleological purposeful attractor. Below is the list (by all means, incomplete) of assorted physical effects which may play a role in evolutionary design at the microscopic and/or macroscopic level of structuring. Same list may be applicable to the ED at the level of micro- and nanotechnology.

4.2.2.1 Quantum tunneling or quasi-quantum (semi-classical) tunneling to a *TELE*ological (purposeful) attractor. In this case it may be possible to skip intermediate trial and error steps in ED and proceed directly to a final workable version of the design. Symbolically, one can ask whether a picking up of a "correct" book from the shelf of Library of Babel (or a pin-pointing of a "proper" segment in the decimal decomposition of pi, or any transcendental number) can be interpreted as a some kind of a "conceptual tunneling" in a multidimensional phase space of all relevant variables (parameters) of the design.

4.2.2.2 Collapse of the wave function is the reduction of the quantum superposition of multiple states to one resulting state. It is one of the key elements of Quantum Computing [4]. In the context of ED its equivalent is the choice (approval) of the final version of the design out of range of trials. Some authors (e.g., Roger Penrose) relate this process to the functioning of consciousness and decision making.

4.2.2.3 Variable range hopping (VRH) in compensated semiconductors can provide another paradigm of "Freedom of Choice" – this time in a solid state system. Because of its random nature (enormous number of quantumly-selected possible hoping paths for each electron), VRH can serve as a generator (and/or simulator) of Natural Creativity. This way VRH opens a broad platform for a freedom in non-living systems (compensated semiconductor – the one which contains both donors and acceptors). Like in a known "Traveling Salesman" problem, there are plenty of (almost) iso-energetic hopping paths for each electron between given initial and final hopping sites.

4.2.2.4 Quantum coherency has numerous examples, such as a build-up of coherency states in lasers, macroscopic quantum effects such as superconductivity, coherency in semiconductor quantum dots, etc. Quantum coherency is also of key importance for systems utilizing superpositions of quantum states, such as Quantum Computers.

4.2.2.5 Multimode optical fibers Mode selection in fiber-optics ("survival of the fittest") – occurs due to (a destructive) interference of other ("wrong") modes.

4.2.2.6 Biological information transfer refers to the co-existence of various information transfer paths in subsystems of bio-systems (e.g. , neural, immune, reproductive, digestive, respiratory [sub]systems of the functioning organism). Recent reports (Graham Fleming, Gregory Engel) suggest that efficiency of the photosynthesis may be based on a natural Quantum Computing search algorithm. Likewise, Quantum Computer controlled Casimir effect (short range attractive forces) may provide an actual "constructing tool" for assembling biological structures at atomic (nanoscale) level.

4.2.2.7 Spontaneous symmetry breaking (SSB) was briefly discussed above. To that, one can add the effect of Anderson Localization in disordered systems. In all these cases the system in question is originally in a mixed quantum state (superposition in multidimensional Hilbert Space) which then spontaneously arrives ("decays") to one of many possible final states thus, in a sense, exercising its "freedom of choice". The search for most viable design solutions in ED sometime proceeds by a conceptually similar route (often without conscious realization of that). Another example of SSB is Jahn-Teller effect which is a spontaneous complification of a system at a microscopic level due to interaction between nuclear and electronic motion. In ED it may have nano-technological applications such as atomic-level memory cells.

5 Informatic aspects of natural and artificial design

In essence, within the conceptual frame of classical physics the Universe is seen as a giant machine. Presently, a competing paradigm is emerging. Within this paradigm the Universe is a giant computation [3]. This idea is gaining strength, in particular because of fast progress in Quantum Computing [3, 4] and Quantum Communication Systems. Ideas of quantum delocalization, quantum nonlocality, teleportation, quantum reduplication are all enter the mainstream of ED.

5.1 Evolution is much more than a mere biology

Some authors trace the beginning of evolution to the Big Bang itself, which is often interpreted as a starting point of the Universe. Other theories see the Mega-Universe in terms of space, time and infinite dimensionality (infinite number of Parallel "mini-verses"). Mega-Universe (sometime called Megaverse) in this connotation means the (presumably infinite) totality of all mini-verses, each one of them originating through "its own" BB. The number of such miniverses may exceed any finite number, even tower-exponential [7], and may turn out to be an actual infinity, perhaps even uncountable infinity (Aleph One or higher) in terms of Cantor's Set Theory. Physicist Lee Smolin suggests that similar mechanism may be at work for the evolution of BB universes (miniverses).

5.2 Natural and engineering design and technological progress

Ergoidicity presumes a huge range of potentially available states – in this case by "states" we mean particularities of specific ED. Common ED over the millennia of its development follows this path (even without using ideas of ergodicity explicitly). Natural phenomena provide numerous hints for ED. For example, light confinement in fiber optics can be found in some organisms and plants. Mimicking Nature in ED expands database of "already available" functional parts and components of the design. Like in any evolution by selection, not everything works well because both Nature and humans are prone to failures.

5.3 Delayed inventions

A famous example of standard QWERTY keyboard (which is <u>not</u> the most ergonomic and fast, but virtually the only one universally used throughout the whole world) is generally well known. This is a case of a "lock-in" effects (technological hysteresis) when factors other that technology as such (market forces in this case) prevent introduction of more advanced ED. There are many other examples of discoveries and inventions which were made much later than they could have been made.

Lenses and spectacles (concave and convex) were known for a few centuries prior to somebody figured out that the combination of two lenses them can produce a telescopic effect. Hence, telescopes could have been invented in 13th century instead (at least as far as we know) at about 1600. Likewise, stirrups (a very simple idea) which can greatly increase the efficiency of military cavalry, were not know in Ancient Rome. Long delay (many centuries) in adopting very efficient positional number systems (as opposed to highly inconvenient Roman numbers) was a strong impediment to a progress of science and technology in the Middle Ages. Even such mathematically simple idea as one-sided Mobius Strip was discovered only as late as 1858. Amazingly, that this technologically useful (several applications) construct was, somehow, overlooked by all great scientists before that (at least, there are no known earlier mentioning of it).

5.4 Random aspects of creativity and engineering design

Randomness is probably the most misunderstood feature of ED and human creativity in general. From quantum uncertainty to a (human) freedom of choice almost everything is subjected to randomness. Practically all aspects of human activity from cooking to literature, poetry, arts, and music are domains of randomness. There are always zillions of ways how words and objects can be combined. The question is how Randomness can be usefully harnessed in a somewhat controlled way towards some targeted goal, such as ED or scientific research. Below are some comments towards this end.

5.4.1 Supervised randomness
Random number generators which are based on some deterministic mathematical procedures inevitably possess some hidden correlations [9]. Alternatives are Random Generators based on some physical processes such as isotopic jets [8] or radioactive decays. However, once random message (strings of numbers, random texts, etc) is produced, it can then be "supervised" (edited) with a goal of enhancing its meaning value.

5.4.2 Randomness and compressibility
Standard mathematical definition of random string presumes its incompressibility. By that it is meant that such a string cannot be produced by a computer program shorter than the string itself [5]. For that matter, arbitrary long decimal string of digits of pi is not random (even if it appears so), because programs to compute pi with arbitrary precisions are relatively short.

5.4.3 Brainstorming and discarding
While the idea of supervised randomness may appear self-contradictory at first glance, it, in fact, forms a core of brainstorming sessions. In the latter a group of people throw out numerous ideas without criticizing them. The degree of relevance or usability of these ideas may vary broadly. This is followed by some editing and eventual synthesis and validation towards the sought applicational goal.

5.4.4 Randomly generated texts
The idea of machine-written research papers may appear abhorrent, and yet some attempts to do precisely this has recently been tried (the so called "Dada engine"). At this moment, these experiments are largely confined to the Internet. For that, random generators are used to create grammatically valid sentences loaded with scientific terms. While for most part so produced texts are meaningless, upon the proper editing and "brushing" some of them emerge as original and interesting thoughts and applicational offerings.

5.4.5 Sokal hoax
People who use Tarot Cards claim some meaning in obtained random spreads. To mock such "New Age" activities, physicist Alan Sokal has published (what he thought) is a meaningless paper. However, what he got was the opposite to what he expected. Many read his paper with excitement and interest. Thus, the Sokal hoax may be less of a hoax than its author intended it to be. Contrary to what Sokal tried to proof, seemingly random jumble of terms ("Conceptual Tarot") can sometime open new and stimulating vistas for contemplation and applicational use.

5.4.6 Randomness and arts

Strange combinations of objects are often found in arts, especially in Surrealism (e.g., Salvador Dali). While at times such images are ambiguous and difficult to interpret, they almost invariably are thought-stimulating. Some ideas for ED were drawn from that (for example, flying machines in art of Hieronymus Bosch, ca. 1450–1516).

6 Conclusion: technology, engineering design and human values

While we can only guess the ultimate goals of Nature (or even if there are any), in human terms our personal values usually affect most of what we do. Dynamics and motivations of ED are no exceptions. Ethical considerations often (though certainly not always) play some role as well, especially is such ethically sensitive areas as genetic engineering and (potentially possible) cloning of humans. Literature (especially, science fiction) and visual arts are often serve as test grounds of risky and disturbing ideas, such as mind control, artificial lifeforms, etc. Inherent value of randomness as a stimulator of imagination for human creativity and ED cannot be underestimated.

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