Untamable Curiosity, Innovation, Discovery, and Bricolage

Are We Doomed to Progress to Ever Increasing Complexity?

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A trapper in the eighteenth century needed a box of matches, a gun and a knife, and perhaps, a tent and a canoe or a dogsled to survive in the wilderness. Today, almost anyone of us would feel uncomfortable without an additional GPS, a mobile phone with Internet access, a medicine chest with at least aspirin, an antibiotic as well as a serum against snake bite, and a lot more to master the same situation as the backwoods contemporary of George Washington. Only a short time in the span of human history has passed since the glorious days of trapper life, and no one would seriously doubt that complexity of life has increased enormously since then. This essay is an attempt to combine messages from three sources: (i) a book on scientific innovation, society, and the future written by Helga Nowotny [1], (ii) an article on a model for the evolution of technology by Brian Arthur and Wolfgang Polak [2], and (iii) François Jacob's concept evolution and tinkering [3] that has been recently revisited, for example, by Denis Duboule and Adam Wilkins [4].

Apart from a marvelous collection of many interesting details, Nowotny's book draws an ambiguous image of the future that, with a little modification, could be cast into the following sentences: Scientists and science as a whole are driven by curiosity, which is seen as an insatiable driving force leading to innovation. Success and progress in science are measured in terms of innovation, and cumulative innovations drive the Western World and, because of globalization, the World as a whole, into a fragile future full of risks and dangers. Fears of the future derived from the observed fast changes make societies ambivalent to scientific progress, torn between hopeful acceptance and vigorous rejection of novelties. Although one feels the unspoken desire to stop the whole "malicious" development, Nowotny accepts the innovation process as inevitable and pleads for a new synthesis of science, technology, and humanities. Adding to Nowotny's suggestions, we might argue that curiosity has been genetically inherited from our primate and mammal predecessors and like innovation or progress it is a priori neither good nor bad. In other words, curiosity as such is an evolutionarily selected trait and not a moral category.[1]

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[1]*By this I do not want to say that progress has not been beneficial to mankind. After all the life expectancy of man in the developed societies has more than doubled within the last two centuries and is much longer than in third world countries. I am only indicating that innovation can resolve a plague of human society or lead to a new kind of especially nasty bomb.*

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The article by Arthur and Polak [2] (this issue of *Complexity*) introduces a model for combinatorial evolution that is assumed to mimic development in the world of technologies. New devices are constructed by combination of modules from a collection of simpler tools. Additional combinations yield new combinations that allow the design of an almost infinite number of objects of increasing complexity. In their article, Arthur and Polak show that even random assembly of simple logical elements leads to surprisingly sophisticated logical operators through a process of evolutionary self-organization. (For a more biologically motivated model based on "digital organisms" developing logical functions of increasing complexity see [5].) Adding selection through economy and society in addition to variation through combination indeed provides a plausible model for the development of technologies. It is worth mentioning here that Jacques Monod [6] saw the evolution of technologies as a case for Darwinian selection and considered it an even better example than biology itself. A very attractive feature of the model [2] is that technologies have finite life times as in the real world, and their replacements follow the well-known rules of self-organized criticality [7]: There are many small events opposed to few large ones, and the distribution of events follows a power law as found with, for example, avalanches on sand piles [8], intensities of earth quakes [9], extinction of species in paleontology [10], or allometric scaling in biology [11]. Mutual interdependence caused by multiple usages of the same building blocks causes large collections of objects to become obsolete simultaneously when a key device is replaced by new technology. The resulting "avalanches of replacement" were discussed by Joseph Schumpeter [12] and characterized as "gales of destruction." As a consequence, some technologies disappear completely: In illumination technique, the pine-torch was replaced by the candle, the candle by the incandescent mantle, and finally, the incandescent mantle by the electric light bulb. In electronics, to name one example, the tube has been almost completely replaced by the transistor. The introduction of a new technology often reduces the size of the device and to a certain degree, sometimes the complexity. A comparison of the mechanical calculator, the huge ancient machine fully equipped with tubes and the modern computers based on silicon chip technology serves as an example.[2]

A third, but not less important piece fitting into the puzzle of innovation, is biology. Molecular genetics and genome research in particular have provided many convincing hints that evolution and development are the result of bricolage or tinkering [3,4] rather than the outcome of rational design. Nature does not perform like an engineer. She does not design from scratch, but builds new things by combining parts from a repertoire of already existing and readily available modules. The molecular data collected within the last 30 years brought completely new insights into evolutionary developmental biology (evo-devo; see for example, [13,14]): The genetic regulatory system of an organism is an exceedingly complex network and gene products fulfill multiple functions in the sense that the same molecules are used in the cell or in the organism for many different purposes. New body plans and new phenotypic traits do not arise from new molecules but from reuse of existing molecules in different combinations. Multiple usages, as in the case of technologies, make the reaction networks more complex and required more sophisticated means of regulation [4]. There is, however, one major difference between biological and technological evolution. Solutions to problems, once established, are almost never replaced in biology: Our cells use the same synthetic machinery for the production of biopolymers as the last common ancestor of all terrestrial life. This hypothetical unicellular organism is thought to be a descendant of the first cell called the progenote [15]. The interior of present day cells, in particular the cytosol, matches the conditions in a primordial sea: no oxygen and specific cation ratios Na^+/K^+ and Mg^{2+}/Ca^{2+}, much better than those of our present day oceans [16]. The development of the vertebrate, insect, and mollusk eyes follow genetically traceable phylogenetic paths originating from one genetic regulatory device and are presumably derived from a single early photosensitive pigment [17]. Many other examples can be found for the build-upon-the-past principle of Nature. Unlike in the evolution of technologies the machinery driving the development toward higher complexity has never been reset in biology by the introduction of simpler tools based on new technology. The marvelously complex system of genetic regulation, signaling, and cellular metabolism is the consequence. This incredibly interwoven network is precisely what makes it so difficult to understand cells and organisms [18].

It seems useful in this context to make a distinction between discovery and innovation: Discoveries introduce something completely new into the system, for example, the semiconductor in modern technology development, or, in Nature's "discoveries" during prebiotic evolution, the elementary protein folds like the α-helix or the DNA double helix. Innovation, on the other hand, can be understood as the combination of already existing elements in a new context. The two publications mentioned above [2,5] are dealing with such innovations. In this sense evolution of technologies is a balanced mixture of both discoveries and innovation: The former introduce new technologies and allow for development of devices from scratch, whereas the latter is responsible for the construction of complex ma-

[2] *As a rule, an increase in the complexity of the infrastructure to produce the device compensates for less complex handling of the novel technology: For the pine-torch and the candle you need a fairly simple production facility and a match; for the incandescent mantle light you need the factory producing the lamp, the match, and kerosene; for illumination by the electric bulb you need the bulb producing company, the wiring of the house, and a power station.*

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chinery by combinatorial evolution. Natural evolution, on the other hand, seems to restrict the "discoveries" to the early phases of development on new hierarchical levels of complexity, which are the periods of the so-called major transitions [19,20].[3] The rest seems to be combination through bricolage.

Eventually, we shall try to put all three different issues together and speculate on the origin and the consequence of untamable curiosity.[4] To search the unknown and to hunt after innovation seems to be a trait that we share, to a different degree, with all mammals and it could be, perhaps, a result of brain evolution. I think curiosity is a selective advantage as long as a large part of the population is not killed because of uncontrolled progression into dangerous territories, and avoidance of this fatal habit is presumably regulated by the education of animal or human progeny through parents that wean the youngsters away from too curious searching. Bricolage leading to innovation increases complexity because of the combination of modules to networks with interactions on all scales. In technological evolution we can reset the "clock of complexity" by discovering the elements of a new technology. In Nature this seems to be very hard if not impossible. As far as biology is concerned reducing complexity would require whole phyla to die out because only then evolution may restart at the less complex root. How can we try to find a hint for the answer to the question in the title? If evolution of human societies as a whole is closer to biological evolution, we cannot escape the race for developing more complex societies with more and more bureaucratic overheads. If, however, societies developed more similarly to the mechanisms observed in technological evolution, new qualities of human relations between individuals in societies could succeed in resetting the "clock of complexity."

[3] *Such hierarchical levels of complexity are evolvable molecules, cells, multicellular organisms, individuals, societies, etc.*

[4] *The attentive reader might have realized that I used "untamable" in the title rather than "insatiable" as the adjective of curiosity. This notion should point toward an open-ended evolutionary process behind the observed development that escapes attempts of controlling on a global scale.*

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