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Book review: James A. Shapiro's *Evolution: A View from the 21st Century*

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This[1] is an extraordinary book in many respects, not least for its sheer number of references. While the ideas are presented in four parts over a mere 147 pages of the main text, the references number no less than 1162. As the material can often be quite technical, the author has included an extensive glossary to help non-specialist readers. He wisely prefaces the book with a note assuring those readers that they can skip the very technical sections and read only the Introduction, along with the beginning and concluding sections of each part. Those wishing to explore particular topics in more detail are invited to visit a companion website for the book or the author's own website, both of which provide suggested readings for a general audience. So the book goes to considerable lengths to cater for specialists and general readers alike. As the bulk of the voluminous references consists of research presented in specialist journals and books, the technical discussions are thoroughly and meticulously documented. And the opening and closing sections of each part are written in a clear and coherent style that will undoubtedly be appreciated by the non-specialist.

The broad perspective implied in the book's title could easily mislead readers unfamiliar with James Shapiro's work. As a specialist in molecular biology, his interest in evolution has mainly focused on microbial organisms and cells, and while occasionally describing or theorizing about the evolution of plants, insects, and mammals, including humans, this book retains a focus on molecular biology. But anyone interested in evolutionary processes will learn much, as the book provides very substantial evidence for the neglected but vital activities at the cellular level that are already known to apply in the growth and evolution of more complex organisms.

When the precise structure of DNA was discovered in the 1950s, Darwin's theory was at last furnished with a clearly identifiable means of heredity that could conceivably account for all biological evolution. This set a new theoretical paradigm that came to be known as neo-Darwinism – best represented in the "gene's eye view" proposed by William Hamilton but later popularized by Richard Dawkins. However, this attempt to reduce the source of evolutionary change to a single mechanism has always been difficult to reconcile with the behavior of organisms observed in the laboratory or in their own natural habitats. These observations have led to the formulation of alternative theories that provide a much richer account of the myriad ways in which organisms themselves actively alter the structure of their environments. By making the environment more conducive to their own development, or that of their progeny, organisms often contribute to their own survival in ways that the "gene's eye view" cannot adequately capture.

Consistent with similar arguments by proponents of systems biology, Shapiro points out that genes alone are incapable of any action, let alone self-replication. The activities involved in replication, repair, and the production of novel functions are produced by "natural genetic engineering." Philosophers in particular may be disturbed by that description in the belief that it implies the need for an engineer. However, Shapiro stresses that these adaptive behaviors are not reducible to the effect of any single attribute or component in the cell, but typically rely on the co-ordinated actions of different functional elements. Many of the technical sections go into great detail explaining how cells function and develop in much the same way as any intelligent organism, i.e. by sensing the environment, transmitting signals, and even "decision-making."

In Part I, Shapiro uses several apt examples to illustrate how cells exhibit this apparent intelligent agency. Drawing on Jacques Monod's experiments, which began even before the structure of DNA was properly understood, Shapiro describes how bacteria that had two types of sugar available – one promoting high growth (glucose), the other low growth (lactose) – consistently consumed the high-growth sugar before pausing and then consuming the low-growth type. This was observed even when the two types were mixed in different proportions. At first glance, a biological process that produces such a predictable result from only two possible responses would seem more plausibly interpreted as a simple case of tropism, as when a plant grows towards the strongest light source, or its roots grow towards the richest source of nutrients. Even more parsimoniously, such processes could be seen as analogous to purely physical laws, for example as similar to the way metals respond to magnetic forces. However, discoveries revealing the numerous, complex actions behind this bacterial response show that it is more analogous to the logical Boolean circuits in computer programs.

These discoveries have shown that sugar metabolism in the *E. coli* bacterium is in fact governed by "at least five general principles of cellular information processing and communication within the genome" (9). Shapiro's description of these principles is quite technical but essentially and effectively shows how they involve sensing and signaling between proteins and other molecules, ultimately resulting in responses that are conditioned by the data obtained. This is also well-illustrated in Shapiro's example of how DNA damage is repaired in a two-stage process: during replication, misplacement of a nucleotide in the strand is detected by a sensory mechanism which then activates the correction procedure. Any subsequent errors are detected and fixed by different proteins performing dedicated tasks in sequence.

Shapiro also cites the phenomenon of programmed cell death as an example of "decision-making," as it is not a hard-wired response but the result of variable signaling actions between and within cells. Programmed cell-death allows bacteria to "maintain genetic stability and ensure survival of a proportion of the cells in multicellular populations" (23). Cells evidently use feedback mechanisms that regulate their functions. And many of these mechanisms may work in ways that are consistent with basic Boolean operations. So in these respects at least, Shapiro's examples present a convincing case that cellular growth and reproduction rely on actions of sensing and signaling that enable adaptive responses. While cells do not possess the sensory apparatus of complex organisms, or the brain that allows genuine language and self-reflection, they evidently use cognitive processes that resemble those of artificial intelligence.

Progress in artificial intelligence, particularly in the design of "neural" algorithms, shows that the activity of learning is itself an evolutionary process that is not confined to capacities in the neo-cortex. Artificial analogues of these biological learning mechanisms enable robots to discover an optimal series of maneuvers to reach a specific goal. With continual feedback obtained through trial and error, the robot progressively updates its original program, effectively "overwriting" it with new conditional rules. Despite the progress and respectability of this evolutionary paradigm as modeled by artificial neural networks, the dominant theory among geneticists has been that "the genome is a read-only memory (ROM) system subject to change by stochastic damage and copying errors" (28). However, the overwhelming evidence that Shapiro and other molecular biologists have accumulated over several decades simply cannot be accommodated by that theory.

This "Central Dogma of Molecular Biology" as Crick was hastily content to name it, was always problematic as it was formulated on the basis of limited observations about protein synthesis. But major revelations in understanding the workings of the genome and epigenetic functions now warrant a significant theoretical shift in viewing the genome as "a read-write (RW) memory system subject to non-random change by dedicated cell functions" (28). It is worth noting that this perspective is not entirely new or as radical as it might sound, as it coheres with earlier conceptions of evolutionary mechanisms such as that proposed by Baldwin at the end of the nineteenth century. While Shapiro does mention these earlier views, readers would have benefited from some reference to the most prominent of them, as many of their insightful observations have now been rediscovered in the light of our contemporary knowledge.

The central problem faced by adherents of the "Central Dogma" is explicit in Shapiro's use of the computer analogy to indicate that genome changes are largely driven by self-regulating cellular activities and therefore do not rely on random mutations to evolve. And while Shapiro remarks at the very beginning of the book that "the accidental, stochastic nature of mutations is still the prevailing and widely accepted wisdom on the subject" (1), this is something of an exaggeration and is liable to add to a common misconception about randomness in evolutionary change. Even the most prominent popularizers of the neo-Darwinist view[2] recognize that organisms themselves actively restructure their environments, thereby creating selection pressures that favour the evolution of genotypes best adapted to that changed environment. Thus, while insisting on random mutations as the main *source* of evolutionary change, the conventional view also acknowledges that the effects of those changes need not be random.

To some extent then, in recent decades the modern synthesis has itself been forced to loosen its central tenets to better account for the observed frequency of genetic selection pressures created by organisms themselves. The problem with the prevailing view is not that it fails to recognize the role of non-random changes in evolution. Rather, it fails to appreciate how such processes at the cellular level are essential to the normal life cycle of organisms. In terms of Shapiro's computer analogy, neo-Darwinism fundamentally underestimates the read-write capacities of living cells.

It is strikingly ironic that strict adherents of the modern synthesis should have such difficulty in giving due recognition to these well-observed capacities, especially given that they are fully consistent with a Darwinian account of heritability informed by the functional properties of DNA. After all, these capacities are vital functional mechanisms and as such are themselves *genetically inherited.* So there is no sense in which their operation can be seen as violating either Darwin's theory or modern genetics.

In Part II, Shapiro gives very detailed descriptions of how these vital functions operate as part of the normal life cycle. He does an admirable job in attempting to explain the complex nature of these interactive processes. While the glossary certainly helps to guide the general reader through this relatively long section, many will find the technical discussions difficult to follow. However, the example of the mammalian adaptive immune system, while no less technical in description, is particularly instructive and its significance can be easily appreciated from Shapiro's introductory summation. This immune response can only evolve and work efficiently by quickly learning to recognize and act against "a virtually infinite and largely unpredictable range of invaders" (66). As Shapiro notes, DNA in the germ cells can accommodate only a limited range of proteins, so resistance to all these potential threats could not be inherited via reproduction. But neither could it be achieved through an unstructured trial and error process testing each potential antibody. Instead, rapid immunity is reached by "targeted mutagenesis" where DNA is rearranged by molecular processes that vastly increase the range of potential antibodies and thereby accelerate the evolution of successful ones.

Like the adaptive mechanisms involved in the development of the immune response, the genome can also be restructured by horizontal DNA transfer, e.g. from viruses and by symbiogenesis, where different organisms effectively pool their genetic resources for mutual benefit. As these terms suggest, both processes involve growth and evolution through genetic combinations that do not result from mutations. As the effect of these alternatives to reproductive genome transmission have been largely neglected until recently, in Part III Shapiro discusses their likely role in the evolutionary history of bacteria, plants, and animals. And in discussing how cells themselves evolved these various capacities to actively alter genomes, he notes that modern genome data sequencing has revealed that proteins share functional domains. Clearly, this facilitates and accelerates major evolutionary changes. Adapting protein functions to new activities would not have to occur in a random, piecemeal fashion, as numerous versions of already existing functional segments will be readily available for rearrangement into novel combinations.

The fourth and final part delves further into the means available for generating novelty, but from a more expansive and long range view of evolution that is best captured by use of another analogy – that of systems engineering. Here, readers might pause to wonder if Shapiro has suddenly abandoned the earlier read-write computer analogy. But it appears that he intends both analogies to describe actions at different levels of detail. Cells do not simply receive and copy genomic information but actively rewrite it. Though valid and useful for explaining how cells are agents of evolution, this information-processing analogy does not fully account for the often simultaneous, co-ordinated actions needed to generate and stabilize the structure of novel functions. So the systems engineering analogy is indeed an apt one and of course coheres closely with the well-established theoretical approach of systems biology.

From the vantage point of this more comprehensive systems perspective, Shapiro sketches the idea that many of the cellular and molecular mechanisms responsible for reorganizing genomic functions may also play a heuristic role by orienting the placement of particular recombinations. Again, this idea not only coheres well with research in systems biology, but also with the Evo-Devo research program, the niche-construction process and some interpretations of the rediscovered Baldwin Effect.

Shapiro calls for an urgent paradigm shift that gives due recognition to the evolutionary role of cellular activities and it is certainly well overdue. However, in noting that the journal *Nature Immunology* dedicated its August 2010 edition to “decision-making in the immune system,” he takes this an indication that these ideas have “gone mainstream” (137). This book builds on an already extensive body of work over many decades and fully lives up to its name in providing a view of evolution that should greatly expand future research into this new century and beyond.

Notes

1. All page references in the text are to Shapiro (2011).

2. In discussing the research of Shapiro and others, Evelyn Fox Keller (2000) refers to a paper by Richard Dawkins entitled “The Evolution of Evolvability.” Here, Dawkins himself remarks that he has “been led to think differently as a result of creating and using computer models of artificial life” (Keller 2000, 201). This led him to propose an account of “higher level selection, a selection not for survivability but for evolvability” (218).

References

Keller, E. F. *The Century of the Gene*. 2000. Cambridge, Mass: Harvard University Press.

James A. Shapiro. 2011. *Evolution: A View from the 21st Century.* Upper Saddle River, NJ: FT Press Science.