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The Apian Way

From beehives to burrows, animal building sheds new light on biology.

THE EXTENDED ORGANISM
The Physiology of Animal-Built Structures.
By J. Scott Turner.
Illustrated. 235 pp. Cambridge, Mass.: Harvard University Press. $47.50.

By Kurt Schwenk

GENOTYPE, phenotype, environment: the hallowed trinity of evolutionary theory. If you've had college biology you know the drill: the genotype comprises the set of genes in an organism, the phenotype is its physical manifestation and the environment serves as a kind of Grand Inquisitor, sitting in judgment on the small phenotypic (and therefore genotypic) differences among individuals in a population. "Successful" individuals are those that outcompete others within the environmental arena to leave more offspring, thereby passing on more of their genes to the next generation. Indeed, biologists often define evolution as a shift in gene frequencies within a population over time, and they view phenotypes as little more than clever devices employed by genes to replicate themselves. It is no wonder, then, that evolutionary biology is dominated by study of the genotype-population genetics, quantitative genetics and most recently a tsunami of molecular genetics. Progress in understanding the nitty-gritty of gene structure and function has been extraordinary. So why is it we still know so little about how organisms evolve?

The problem is physics envy. In physics, fundamental insights have been attained through reductionism — the ability to explain complex phenomena by reference to elemental processes. Many biologists, seduced by this example, persist in believing that the complexity of whole-organism evolution can be similarly understood. It was Darwin himself who started us down this garden path by acknowledging that his ignorance about the mechanism of inheritance left a gap in the theory of natural selection. Into the breach swarmed evolutionists, convinced that the key to evolution was the mechanism of inheritance, genetics.

What does our vast knowledge of the genotype tell us, 141 years later, about how organisms change form through time? Not much. Reductionism has not been a bust. It has generated bucketloads of basic knowledge about genes and how they work. But the touted key to phenotypic evolution never materialized. This failure can probably be attributed to the pesky problem of "emergence." A complex system, say a living organism or an ecosystem, has what are called "emergent properties" when its parts interact in unforeseeable ways. The behavior of the system as a whole cannot be predicted from a knowledge of its parts. This behavior "emerges" from the system's inherent complexity. A complete knowledge of every gene within an unknown animal, for example, tells us nothing about what the creature looks like, let alone how it feeds, finds a mate and, ultimately, evolves. These things emerge not from the genes directly but from the cascading web of interactions among molecules, tissues, organs, organisms and environments set into motion only by the production of proteins encoded by the genes. The principles governing gene function may rule within their limited domain, but they cannot be extrapolated to the level of whole-organism form and function, nor to the interaction of organism and environment. These are governed by other rules discernible only through direct study. The key to the evolution of organisms is therefore not to be found in the genotype, the phenotype or the environment; it is in the integration of all, the biology of holism.

Talking about holistic biology and pursuing it are different things. As biologists become increasingly specialized, integrating fields gets harder to do. With his audacious new book, J. Scott Turner shoots an impressive salvo across the bows of narrow thinking. He judges it unlikely that molecular biology will fundamentally change our way of thinking and finds neo-Darwinism "a bit frayed and dowdy . . . with all its best insights behind it." The only way to break out of these doldrums, he suggests, is to dispense with the trinity, specifically the distinction between phenotype and environment. Turner seeks nothing less than "a biology that unifies the living and the inanimate worlds."

A biology of the inanimate? Turner, who teaches at the SUNY College of Environmental Science and Forestry in Syracuse, insists that the line between organism and environment is an "essentially arbitrary boundary." As he painstakingly builds his argument, one progresses from head-scratching to head-nodding. To work this metamorphosis, Turner brings to bear scientific incisiveness, humor and a prose style that makes scientific minutiae fun to read.

Turner turns to animal structures to make his larger point, developing several examples in glorious detail. His thesis is straightforward: if animals manipulate their environment to create external structures serving an essential physiological function, then an organism's phenotype extends into the environmental realm. Termite mounds, for example, function as gas-exchange organs, dynamically maintaining proper levels of oxygen and carbon dioxide within the nest, even as the colony grows. As essentially aquatic animals in a terrestrial environment, earthworms rework the soil with ceaseless burrowing, transforming it into an external organ of water balance. As an accessory gas exchanger, the foamy nest of spittle bugs acts rapidly to dissipate toxic ammonia waste. So where does the organism end and the environment begin?

The title of "The Extended Organism" signals that Turner's book builds on Richard Dawkins's 1982 work "The Extended Phenotype." Where Dawkins sought to show the action of genes outside the body, Turner's focus is "external physiology." But the book is far more than a complement to Dawkins. It stands apart as a remarkably synthetic piece of scholarship.

The book's greatest strength, paradoxically, is Turner's masterful use of reductionism to establish his holistic view. With stimulating explications of thermodynamics, hydrodynamics, electrical circuits, fractals and acoustics, among others, he shows how these processes underlie the workings of animal structures. The structure itself, however, provides the key. It serves as a kind of nexus where elemental processes within the organism commingle with those of the environment. The result is "superorganismal physiology" — a whole greater than the sum of its parts and far more wondrous. Reductionism-holism, phenotype-environment, inside-outside: life is rarely simple, and truth so often dwells in nuance. As Turner suggests, "The relentless rejection of the simple can open up marvelous vistas of new biology to explore." □

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