The New Foundations of Evolution: On the Tree of Life

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Reimagining the Tree of Life in Light of Data from Microorganisms

The New Foundations of Evolution: On the Tree of Life. Jan Sapp. Oxford University Press, 2009. 448 pp., illus. $39.95 (ISBN 9780195388503 paper).

We live on a microbial planet. Microbes have inhabited Earth for an estimated 3.5 billion years, with animals appearing less than a billion years ago and modern humans evolving within only the last few hundred thousand years. Microbes are essential for the cycling of chemicals on our planet and thus play a critical role in global climate change. There are more microorganisms in a human intestine than there have ever been people alive on Earth.

Despite the importance of microbes, our views of biology and particularly evolutionary theory have been largely driven by insights from macroscopic organisms such as plants and animals. This is not surprising, given that humans rely primarily on sight as we interpret the world around us. But developing evolutionary theory on the basis of macroscopic organisms has the potential to mislead. For example, early descriptions of the tree of life that divided organisms into two main branches—plants and animals—are clearly wrong, given the tremendous variety of microorganisms.

In *The New Foundations of Evolution: On the Tree of Life*, Jan Sapp documents the history of how our biased view of biodiversity has led us astray. The book achieves two main goals: (1) chronicling the history of the placement of microorganisms on the tree of life prior to the use of molecular (DNA) data, and (2) describing the contributions of Carl Woese and colleagues in transforming the tree of life with the naming of a third major lineage, the Archaea. Sapp is uniquely positioned to weave together these two themes as he is a professor of both evolutionary biology and of the history and philosophy of science at York University, in Toronto.

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The first portion of the book is instructive and delightful, starting with the ancient plant-versus-animal dichotomy and working through the development of physiological assays and high-powered microscopes as tools to study biodiversity. Sapp documents the parallel rise in post-Darwinian depictions of the tree of life and discoveries of microbial diversity. Although some biologists, such as Richard Owen and Ernst Haeckel, struggled to place microbial organisms on the tree of life, many in the broader field of evolutionary biology dismissed microbes as unimportant.

Among the gems in this part of the book is a brief discussion of the history of bacterial culturing. Apparently, the use of agar for culturing plates came from Fanny Angelina Hess, the wife and assistant of a coworker of Robert Koch's, who learned about agar from a Dutch neighbor who had previously lived in Java. Another of Koch's coworkers, Richard Petri, developed a method of pouring agar into covered glass plates (thus creating the predecessor of the Petri dish) for easy viewing.

The latter portion of the book focuses on the impact of the work of Carl Woese on our understanding of biodiversity. Woese recognized that molecular data could be used to compare diverse organisms even in cases where morphology was not particularly helpful. (It is difficult to use your eyes to compare an elephant with an *Escherichia coli*.) In one seminal paper in 1977, Woese and Fox characterized a portion of the machinery that all living organisms use to make proteins—a ribosomal RNA—and recognized that there was a third major type of living organism on our planet.

This third lineage was originally named Archaebacteria, as these organisms were initially isolated from extreme environments—high methane, high salt, high heat—and were believed to represent the descendents of the earliest life forms on Earth. These organisms are now known to live in a diversity of extreme and common habitats, and are no longer viewed as representatives of early life. As Sapp explains, these organisms are now referred to as the domain Archaea to distinguish them from the two other domains of life, Bacteria and Eukaryota. It is evident from the rich detail in this part of the book that Sapp spent considerable time with Woese's writings—his published manuscripts and correspondences.

I suspect that writing about the history of more recent events is challenging because we do not yet know where particular chapters end. Sapp does mention some of the concerns and controversies surrounding the three-domain tree of life. These include the growing evidence of the role of lateral gene transfer in shaping the tree of life. Sequencing genes beyond the ribosomal RNAs has revealed ample evidence of the transfer of genes, and sometimes entire genomes, among

diverse lineages. Similarly, analyses of multiple genes and now whole genomes have engendered several hypotheses in which eukaryotes arose through some kind of fusion or symbiotic event between an archaeon and bacterium, contradicting Woese's view that the three domains descended independently from a common ancestral "progenote." It remains to be seen what impacts these data will have on future depictions of the tree of life.

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THE MECHANICAL WORLD OF MICROORGANISMS

Living at Micro Scale: The Unexpected Physics of Being Small. David B. Dusenbery. Harvard University Press, 2009. 448 pp., illus. $51.50 (ISBN 9780674031166 cloth).

Our everyday experiences help us develop intuition for basic physical and dynamical processes. For example, when swimming, we take it for granted that we can glide significant distances after pushing off from the pool wall. However, when we then try to apply our intuition to the world of motile microorganisms we run into surprises. If microorganisms attempted to glide through water, they would come to rest after moving only about an Angstrom; they would never get anywhere! The book *Living at Micro Scale: The Unexpected Physics of Being Small* summarizes the basic mechanical features of life at the scale of microorganisms and includes a broad range of fascinating topics that are discussed qualitatively and quantitatively. The world of motion is dominated by the viscous (or frictional) features of any flow—which engineers, mathematicians, and physicists refer to as "low Reynolds number flows"—and encompasses the dynamics of bacteria, phytoplankton, algae, and many other kinds of single cells or cell clusters.

Living at Micro Scale covers many topics, and is written in a well-organized and refreshing style, so there will be new ideas for physical, mathematical, and biological scientists to explore. A distinguishing feature of the book is the author's continual attempt to provide quantitative guidelines to basic aspects of size, shape, type of locomotion, and chemical uptake rates. Author David B. Dusenbery has written broadly on quantitative features of the dynamics of microorganisms over many years. In this book he synthesizes his work and that of many other scientists who have been captivated by the physical world of living microorganisms. I believe that some aspects of the book will be of interest to almost any reader, though some comfort with quantitative discussions is required.

The book is structured into four main parts: physical ideas for thinking about mechanics of size and shape at low Reynolds numbers, physical ideas that affect various modes of locomotion through fluids, orientation to different gradients of stimulants, and finally, the various modes of interactions between microorganisms. The writing is clear and the book is logically organized. Occasional historical remarks serve to remind the reader of important landmarks in our understanding and discovery of the world around us. One of the book's strengths is that Dusenbery makes continual use of quantitative, mostly algebraic relationships, giving the book a distinct place in the literature. Even nonquantitative readers are likely to appreciate conclusions extracted from Dusenbery's arguments, but I did wonder whether some other format of presenting the main results would have been useful for readers less comfortable with the physical and mathematical principles.

In such a wide-ranging discussion, incorporating a large set of topics from classical physics, it is inevitable that a specialist reader would find some of the quantitative arguments in this book misleading. I found myself making a number of remarks of that type when reading about fluid mechanics in the text, and I imagine the knowledgeable microbiologist might feel similarly about some features of the biological discussion. However, the main message in every section is generally clear; Dusenbery has a gentle style for presenting an argument aimed at establishing quantitative trends and relationships as well as for identifying questions involving "optimization." As such, the book will provide a wide and rich set of examples for most any type of biomechanics course. It has much the spirit of the biomechanics books wonderfully written by Steven Vogel, though Dusenbery goes further in bringing in quantitative arguments.

As I read *Living at Micro Scale,* I recognized that in some sense, there are two distinct audiences for this book: (1) physical scientists interested in quantitative aspects of biofluid dynamics in general and swimming microorganisms in particular, and (2) biological scientists comfortable with algebraic arguments who seek a mechanistic understanding of the microbiological world at the scale of individual cells. It is precisely a result of these two distinct audiences that I think many of the quantitative arguments would have benefited from figures and pictures and a more transparent definition of variables; nonquantitative readers may find the lack of diagrams a significant hurdle to understanding the text.

A second, small point of confusion results from several instances in the book where Dusenbery uses the term "relative velocity" or "relative speed" (together with the symbol *U,* commonly used for velocities) to refer to a speed per unit length, which a physical scientist would refer to as a (shear) rate. Additionally, one major shortcoming of the book is the lack of high-quality (color) images of

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