model strongly interacting particles as rubber bands.

Nothing is perfect, of course. Some of the key points really need a longer explanation in order to make sense to an unprepared reader. I think anyone coming fresh to the cosmological constant here would struggle, for example, especially as the idea of this long-range repulsion is introduced before any of the other material about cosmology. Also, Susskind is sometimes happy to use more sophisticated concepts that may stump nonmathematical readers. An example is plotting a "two-dimensional" landscape as a surface with the Higgs field depending on x and y coordinates that are the electric and magnetic field strengths. This leap of casting the quantity of interest as an abstract space is automatic to a physicist, but a little more sympathy for the novice at such points might have helped.

Also, I was less than happy with some of the description of cosmology. Susskind seems to think that astronomical data have confirmed the reality of inflation, which is not so (although inflation is undoubtedly consistent with current observations). In terms of history, Edwin Hubble gets the usual overexposure, and it was amusing to read a detailed description of how Hubble measured redshifts, whereas in fact almost every redshift Hubble used was measured by Vesto Slipher, who had established the general tendency for galaxies to be redshifted by 1917 (compare Susskind's assertion that in 1917, "as far as [Einstein] or anyone else knew, the galaxies were stationary").

Finally, the language of the book will often seem a little cryptic to non-American readers: What is a BB ball? At least a "Rube Goldberg machine" is explained in the index, although all British readers will of course know that the inventor of absurdly elaborate machines was Heath Robinson, who was Goldberg's elder by nine years.

These obligatory small criticisms should in no way detract from Susskind's tremendous achievement. This book is a fine piece of popular science writing, but it is particularly significant for the timeliness of its message. Susskind emphasizes that the whole structure of the universe requires an active Creator no more than does the human eye or the temperature of the Earth. At a time when more and more people seem happy with a creation that took place 6,009 years ago, this lesson needs repeating.

In the end, however, good though this book is, I was left feeling that the argument was not carried to its logical conclusion. Despite his justified scorn for intelligent design, Susskind retains a hint of this worldview in his own attitude. It was Galileo who said that the book of Nature is written in mathematics, and almost all physicists subscribe to this view. When we contemplate the power and simplicity of constructions like general relativity, there is a temptation to carry intelligent design to an extreme in which God wrote the equations, from which all else follows. Frequently this perspective is quite explicit, as with Einstein (recall Bohr's admonition, "Stop telling God what to do!"). The landscape picture derails this thinking to some extent, but Susskind just transfers the quasi-religious awe to string theory, whose mathematical results he repeatedly describes as "miraculous."

But if life on Earth is a random accident in a universe where only chance yielded laws of physics suitable for life, why stop there? Perhaps string theory itself is nothing special and only part of a wider spectrum of possible prescriptions for reality. If the search for a unique and inevitable explanation of Nature has proved illusory at every step, is it really plausible that suddenly string theory can make everything right at the last? Reading Susskind's book should make you doubt that possibility, in which case we may have reached the end of the search for underlying simplicity that has driven physics since the beginning. A comment made by Steven Weinberg in his 1977 book *The First Three Minutes* sums things up well: "The more the universe seems comprehensible, the more it also seems pointless." Pointless to look for meaning in our existence in the universe, and also (according to Susskind) pointless to look for meaning in physics. To a physicist, this is a pretty depressing conclusion, but there is some consolation: The beauty we perceive in the laws of physics perhaps tells us as much about the human aesthetic response as it does about any fundamental design of the universe. In short, physics is a human creative art on the same level as painting and music, and that is reason enough to be proud of what the subject has achieved.

John Peacock is a professor of cosmology and postgraduate coordinator in the Institute for Astronomy at the University of Edinburgh. His research interests, which are in theoretical and observational cosmology, include large-scale structure, galaxy formation and evolution, evolution of active galaxies, and gravitational lensing.

BIOLOGY

Why We Age

Kimberly Hughes

THE LONG TOMORROW: How Advances in Evolutionary Biology Can Help Us Postpone Aging. Michael R. Rose. xiv + 174 pp. Oxford University Press, 2005. $26.

In an article published in 1990 in *Biological Reviews* (65:375–398), Zhores Medvedev of the National Institute of Medical Research in London reviewed more than 300 biological theories that have attempted to account for senescence—the progressive and general deterioration that accompanies aging in humans and most other multicellular organisms. Most of these ideas are based on specific molecular or physiological mechanisms, such as oxidative damage or telomere shortening, and are therefore proximate theories of aging. In a sense, these postulates address the question "How do organisms age?"—not "Why do they age?" The premise of Michael R. Rose's new book, *The Long Tomorrow*, is that the ultimate cause of senescence is natural selection and that evolutionary biology holds the key that will unlock the secret of longer, healthier lives for humans.

The evolutionary theory of senescence is based on the idea that natural selection is very effective at eliminating gene variants (alleles) that have deleterious effects early in life but becomes progressively less effective in older individuals. To consider an extreme example, an allele that kills the organism before it has a chance to reproduce will not be passed on to future generations—selection has eliminated that allele from the population. However, an allele that kills an individual only after the organism has successfully reproduced can be passed on to future generations, and it can even increase in frequency if it has some beneficial effect such as increasing fertility. So natural selection can actively lead to senescence, by favoring alleles that have beneficial early effects but deleterious late effects. Or senescence can evolve simply because of the weakness or absence of selection in old individuals. This dependence of the force of selection on age can be demonstrated mathematically, using formal population genetic theory, but it is not particularly intuitive, which has led to a good deal of misunderstanding in the biology-of-aging literature.

Rose, an evolutionary biologist at the University of California, Irvine, therefore takes on a difficult task by aiming his text at those with little or no formal scientific training. It is impressive that, with few exceptions, the book is appropriate for that audience: It is consistently simple, the style is informal, and Rose uses few technical terms and many metaphors and similes. For example, he explains that after acting powerfully in young people to keep genes with devastating early effects rare, "at the other end of life, natural selection snoozes off," having become "an underachiever, like Woody Allen's God in the film *Love and Death*." These metaphors usually work, and a lay reader will come away with a better understanding both of aging and of evolutionary biology.

The book can also be profitably read by scientists, even though they are not the target audience. However, it may make uncomfortable reading for many researchers, conditioned as we are to prose that is stripped of any personal dimension. Books written to popularize science typically restrict subjective comments to the offering of social or political opinions and don't usually delve into the author's private life. But Rose's story is intensely personal, despite his claim in the preface that it is not a memoir. Even portions of the text devoted to science describe Rose's own research and that of his close colleagues; the work of others is mentioned only to provide context. In other words, Rose does not attempt a balanced or complete treatment of aging science or of the evolutionary biology of aging. However, if one is prepared to accept the book on its own terms, it is both engaging and illuminating.

Readers versed in evolutionary biology will particularly appreciate the fascinating, often hilarious, descriptions of some of the field's luminaries. The chapter in which Rose describes meeting his intellectual hero, John Maynard Smith, is entertaining, but not purely humorous: It ends in disappointment for the young graduate student, foreshadowing future setbacks and personal tragedies. The description of Rose's Ph.D. adviser, Brian Charlesworth, is spot on, capturing both his intimidating intellect and his zany sense of humor. Descriptions of other scientists are not always as flattering and are sometimes tinged with bitterness. Nonetheless, Rose's concise history of prominent theories of aging will keep both professional and lay readers absorbed and often amused.

The book offers a good introduction to evolutionary thinking and to the evolutionary theory of aging. Rose presents this theory as a triumph of evolutionary biology over its more prestigious cousins—molecular and cellular biology. For those familiar with his previous book, *Evolutionary Biology of Aging* (Oxford University Press, 1991), this perspective will come as no surprise. But scientists getting their first exposure to this take on evolution and aging science will probably be startled by Rose's view of the disciplines that dominated late 20th-century biology. Cell and molecular biologists who lack a thick skin may come away insulted by Rose's numerous gibes. His attitude undoubtedly reflects the difficulties he faced early in his career in getting his paradigm-shifting views of aging accepted by established researchers.

But Rose and his colleagues have succeeded in bringing about this paradigm shift by weight of evidence and prolific publication of articles, mostly in top-tier peer-reviewed journals. Most scientists studying senescence now accept the rather remarkable idea that natural selection accounts for such a seemingly maladaptive trait, although there is still debate over the specifics of some mathematical models and the interpretation of some data. Rose was not alone in his efforts to move evolutionary biology to the forefront of aging research, but as outlined in this book, he was the first to publish compelling data. He has also continued to publish convincing and important experimental verification of the evolutionary models of senescence over the years, and his 1991 book—along with Caleb E. Finch's *Longevity, Senescence, and the Genome* (University of Chicago Press, 1990), which prominently features the evolutionary arguments of Rose and Charlesworth—was instrumental in making the evolutionary theory of aging "mainstream."

One of the best and worst things about *The Long Tomorrow* is that the book itself is not long; on the contrary, with only 138 pages of text, it is very succinct. The entire book can be assigned to undergraduates, who should be able to read it quickly and have no trouble understanding the material. The main drawback is that serious undergraduates will want more scientific heft. Even thoughtful lay readers may be occasionally frustrated by the lack of detail on theories and experiments.

Although some of the metaphors Rose uses in place of the formal mathematics of population genetics work fairly well, I think many readers will still be confused about the underlying logic of these ideas. I know from personal experience that it is quite difficult to explain these theories without recourse to equations and graphs. More extended explanation (and even a graph or two) could have been used to advantage. Rose does provide a glossary and a very useful resource for the serious reader—an annotated bibliography that cites many key research papers and technical books.

One of the best chapters is "Birds and Bees," in which Rose outlines the evolutionary theory that explains why birds live longer than mammals about the same size, why flying mammals live longer than nonflying ones, and why tortoises, trees and social insect queens are long-lived compared with their close relatives. These captivating examples provide the most convincing nonexperimental support for the evolutionary view. Another excellent chapter, "Deadly Serendipity," conveys well the excitement of science by describing how an experimental oversight led to a new and important research endeavor for the members of Rose's lab: determining the relationship between longevity and stress resistance. Science's challenges are also communicated, as when Rose describes the poor reception his ideas received at a scientific meeting he attended soon after moving to the United States from Canada.

After I was asked to write this review, I assigned the book as reading for two different groups: the undergraduates who work in my research lab, and a group of faculty, postdoctoral researchers and graduate students in my department who have an interest in aging. In both groups, the readers who were least familiar with evolutionary biology had the most enthusiasm for the book. Thus Rose is successful both in capturing the imagination of young people with little exposure to formal science and in convincing advanced researchers in other fields that understanding evolutionary biology is important to their science and to their careers. This is a significant accomplishment.

Now is an especially propitious time to get the word out, because evolutionary science is under renewed attack from biblical creationists and advocates of intelligent design. According to a CBS News poll taken in October 2005, only 15 percent of Americans accept that humans evolved without God guiding the process. If more of us follow Rose's lead and explain our research skillfully to the uninitiated, we may be able to increase that number.

Kimberly Hughes is an associate professor of animal biology at the University of Illinois at Urbana-Champaign. Her laboratory is actively involved in evaluating evolutionary theories of sexual selection, mate choice and aging in a variety of organisms, including fruit flies, honeybees and guppies.

HISTORY

Reading the Greats

Chitra Ramalingam

THE DISCOVERIES: Great Breakthroughs in 20th-Century Science, including the Original Papers. Alan Lightman. xviii + 553 pp. Pantheon, 2005. $32.50.

Why is it that *Hamlet* and *Moby-Dick* are universally recognized as great works of art, whereas the original scientific papers of luminaries such as Albert Einstein or Barbara McClintock—containing creative and imaginative leaps just as profound—are seldom read, even by scientists? Troubled by this incongruity, physicist, novelist and science writer Alan Lightman has collected 25 of the most important scientific publications of the last century in a volume titled *The Discoveries*. Ranging from Max Planck's introduction of quantum discontinuity into black-body radiation (1900) to Paul Berg's pioneering recombinant DNA techniques (1972), the discoveries marked by these papers represent exhilarating forays into the unknown. Each paper is accompanied by a short essay by Lightman describing the historical context and the scientists' inspirations and motivations.

Great scientific papers, Lightman insists throughout, are works of art:

> Like poetry, these papers have their internal rhythms, their images, their beautiful crystallizations, their sometimes fleeting truths.... In these papers, we see enormously gifted human beings grappling with the nature of the world.

The Discoveries is thus far more than a lineup of 20th-century science's "greatest hits." It is an attempt to show that reading formal scientific literature can offer a window into the minds of great scientists. Lightman certainly has a point: Great scientific work of the past is rarely encountered in its original form,