

cal principles. To use his words, biomechanics deals with "how, where, and why nature does what engineers do." Its purview is not so much microscopic, as in molecular biology or biotechnology, but rather macroscopic. Never mind DNA, RNA, individual proteins or even cells: Tell us about muscles, tendons and bones, trunks, branches and leaves.

At heart, Vogel is an experimental scientist of the old school who loves to work with apparatus cobbled together from bits and pieces readily at hand. When we first met, he was dropping leaves in a vertical wind tunnel made from a simple blower and a bundle of plastic drinking straws to collimate the flow. His latest book, *Cats' Paws and Catapults*, has that same practical, down-to-earth flavor. It is intended for the inexpert reader.

Unlike his earlier books, such as *Life's Devices* (Princeton U. P., 1988) or *Life in Moving Fluids* (Princeton U. P., 2nd edition, 1994), this one compares and contrasts nature's designs with human designs. In the process, it broadens our appreciation of both. Nature's devices, developed over an enormous time span from random variations culled by natural selection, equips organisms for reproductive success: These devices are wet, isothermal, nonmetallic, curved, pliant. Hu-

man devices are devised to satisfy perceived needs: They are dry, non-isothermal, often metallic, flat, stiff. Nature starts small and lets things grow. Humans start big. Nature's devices are self-replicating and self-repairing. Human devices are neither. Nature's devices are only about as good as they need to be. Human devices enjoy much larger safety margins. So forget about the idea that nature's way is necessarily the better way.

Vogel teaches by example, and packs his book with facts—logically packaged to be sure, but nevertheless of great number—how ligaments stretch, for example, or why teeth continue to work even as they wear, how some insects walk on water, why leaves coil in the wind and so on. Physical rules are applied, but not developed from first principles, and few of the figures show scales; some readers will find these omissions frustrating.

One of the sections that I enjoyed most describes successful human devices inspired by nature. Vogel finds remarkably few examples that survive close analysis: streamlined bodies that move through water, inspired by fish; cambered and warpable airfoils, inspired by birds; papermaking from wood, inspired by paper wasps; extruded textile fibers, inspired by silkworms; telephone transducers, in-

spired by eardrums; barbed wire; chain saw cutters; Velcro.

Overall, this is a mind-expanding book. Most readers will gain a better understanding of technology, as practiced by nature and by humans, and thus appreciate more deeply the worlds that they inhabit.

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Black Holes and Relativistic Stars

▶ Edited by Robert M. Wald
U. Chicago P., Chicago, 1998.
278 pp. \$50.00 hc
ISBN 0-226-87034-0

S. Chandrasekhar: The Man Behind the Legend

▶ Edited by Kameshwar C. Wali
Imperial College P. (World Scientific), River Edge, N.J., 1997. 223 pp. \$34.00 hc
ISBN 1-86094-038-2

Diving into Robert M. Wald's *Black Holes and Relativistic Stars* for me was a little like plunging into a book after having been stirred by the movie. I remember the "movie"—the Symposium on Black Holes and Relativistic Stars, dedicated to the memory of Subrahmanyan Chandrasekhar—to have been a rare combination of touching recollections and genuine scientific excitement. A dozen experts in the field assembled on Chandra's campus, at the University of Chicago, in December 1996, sixteen months after his death, to discuss recent developments in the discipline to which Chandra had devoted most of his final 30 years. The book is a collection of their contributions, providing a warm and lasting legacy of that gathering and a rich survey of an important and rapidly advancing area. The book does not disappoint; it proves as uplifting as the movie.

As several of the authors recount, Chandra's seminal discovery as a young man—that a star with a mass exceeding 1.4 times that of the Sun cannot end as a white dwarf but must inevitably undergo gravitational collapse—met with rebuke at first and then disinterest. Only after the discoveries of quasars and pulsars in the 1960s and of binary x-ray sources in the 1970s did the reality of black holes and neutron stars, and the importance of Chandra's theoretical work, sink in. Chandrasekhar received the Nobel Prize for his discovery in 1983. Today, black holes and neutron stars are

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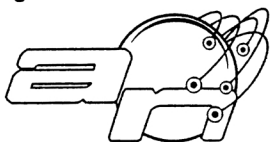
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known to be fundamental constituents of the physical universe. This uniformly well-written volume reviews recent analytic and numerical calculations and summarizes the status of the observational data, focusing on black holes. It serves as a progress report on current thinking in the field by some of its leading and most articulate practitioners.

For Chandra, the mathematical equations were the thing. Not only was he better than anyone else at taming them, but he also had a unique gift for seeing their beauty even as he extracted scientific truth from them. Many of the authors in this volume share this dual appreciation, beginning with the first two, Valeria Ferrari and John Friedman, who deal with the theory of relativistic stars. Ferrari writes about her work with Chandra on nonradial stellar oscillations, showing how the formalism of black hole perturbation theory can be exploited to reveal new modes, couplings and resonances in stars. Friedman surveys the structure and stability of rotating stars, including the very recent and somewhat surprising result that an entire class of axial modes can drive a perfect-fluid star unstable, even when the star has arbitrary slow rotation. Kip Thorne describes what the future detection of gravitational waves from laser interferometers like LIGO (Laser Interferometer Gravitational-Wave Observatory) will tell us about the truly relativistic aspects of black holes and stars, aspects that have yet to be verified by direct observations. Thorne explains why gravitational waves provide the best and cleanest probe of the strong field, curved spacetime around black holes, as well as the most likely means of discovering such new types of exotic relativistic objects as boson and soliton stars. Martin Rees reassures us that black holes do indeed exist by reviewing the compelling observational evidence that supports their presence. The dynamical evidence for a supermassive black hole in the center of galaxy NGC 4258 is striking, although the scenario by which such a black hole forms is not so clear.

Turning from astrophysical implications to the very foundations of general relativity and gravitational collapse, Roger Penrose reassesses cosmic censorship—that is, his famous 1969 conjecture that singularities formed during collapse are always safely hidden inside black holes. Penrose makes clear that he is not convinced by any of the recent numerical simulations that claim evidence for “naked” singularities. He argues instead that the whole question of cosmic censorship—arguably the most important unresolved issue in classical general rela-

tivity—is still very much open. Saul Teukolsky shows how computer simulations can provide significant insight, and even breakthroughs, in general relativity theory. He relates how simulations revealed the unexpected formation of toroidal black holes and how their transient existence proved to be entirely consistent with theorems that at first glance appeared to rule them out. Werner Israel takes us into the singular interior of a classical black hole, where, with the exception of spherical holes, there still remain gaps in our basic understanding.

Field theorists and relativists alike are scrambling over each other these days to uncover the pivotal role of black holes in quantum gravity, and a significant portion of the book is devoted to this hot topic. Robert Wald reviews the relationship between the laws of black hole mechanics and the laws of thermodynamics. Rafael Sorkin follows with a discussion of the statistical mechanics of black holes and suggests an explanation of black hole entropy from a microscopic viewpoint. Reviewing the four-dimensional notion of information, James Hartle offers a self-consistent framework for formulating quantum mechanics in a spacetime containing evaporating black holes. Stephen Hawking discusses black hole information in the context of the no-hair

theorems and black hole evaporation and argues in favor of information loss. Gary Horowitz provides an intuitive summary of the remarkable and unexpected new result of string theory (specifically, D-branes), which allows one to count the quantum states and thus calculate the entropy associated with black holes.

Wald, the editor, symposium organizer and a long-time colleague of Chandra's at Chicago, has assembled an impressive volume. *Black Holes and Relativistic Stars* is a well-organized and provocative series of chapters, each one of which is carefully crafted to appeal to a broad, but technically trained audience. Scientists of all stripes seeking an overview of current directions in the field by some of its most prominent researchers will want to read this book, and many already in the field, as well as graduate students about to enter it, will want to add the book to their collections.

Readers will be especially grateful to Wald for including the personal reminiscences of Lalitha Chandrasekhar, Chandra's wife of almost 60 years as well as a physicist herself and his devoted companion, and those of Kameshwar Wali, his biographer and friend. I was inspired by these pieces and was left wanting to hear more. Fortunately, I had to look no further

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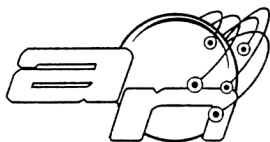
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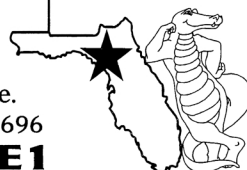
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than *S. Chandrasekhar: The Man Behind the Legend*, newly compiled by Wali, to read the recollections of some 35 of Chandra's former students, colleagues, friends and close relatives. Chandrasekhar was a private person and thinker; he very much shunned the limelight. As Wali reminds us, his was never a household name, nor was he a media persona, unlike some other influential scientists of his time. Yet this volume attests to the fact that he was deeply revered, especially by the young scientists with whom he was delighted to interact. The stories and anecdotes that fill this touching volume reveal that Chandra's extraordinary devotion to science, his breadth, modesty and wit, made as much an impression on those who knew him as did his scientific insight.

From more than one account, including another from Lalitha Chandrasekhar, we are reminded that the acclaim Chandra ultimately received was preceded by a few bitter experiences. He was publicly ridiculed at the Royal Astronomical Society in 1935 by Arthur Eddington, his mentor, who would not accept the inevitability of catastrophic collapse; he was refused the right to lecture in the physics department at Chicago by a dean who was blunt in objecting to having a "black" scientist from India lecture in his department. (University president

Robert Hutchins intervened to overrule this outrage.) Chandra was able somehow to draw on the same inner fortitude that he used to subdue the most intractable of mathematical equations to overcome these early injustices.

By the end of *S. Chandrasekhar: The Man Behind the Legend*, the reader recognizes that Chandra's friends and colleagues, like his life and work, spanned many decades, several generations and many different intellectual passions. He lived for 85 years, but he never really got old. He died in 1995, but this inspiring volume proves that his memory and influence will be with us forever.

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The Cambridge Quintet: A Work of Scientific Speculation

John L. Casti
Helix Books (Addison Wesley Longman), Reading, Mass., 1998.
181 pp. \$23.00 hc
ISBN 0-201-32828-3

Many of us would enjoy an excellent dinner, accompanied by sparkling conversation on a matter of profound in-

terest, with truly luminary companions. We rarely, if ever, enjoy such a meal. John Casti's *Cambridge Quintet* conjures such a dinner, transporting us during the summer of 1949 to Charles Darwin's old suite at Christ Church College of the University of Cambridge to hear an illustrious quintet of diners challenged by the notion of machine intelligence: Can it exist?

Casti is a well-known lay and professional expositor of nonlinear applied mathematics and its manifestations in complexity and chaos theory. The meal he offers (the concept and the subject matter) is tasty and nutritious and should appeal to the appetite of any philosophically inclined scientist. I know of no other short work providing such an engaging review of or introduction to artificial intelligence. But, as with many a real meal, the service is flawed.

The imagined participants are C. P. Snow, novelist, British civil servant and physicist and, in this case, the host; Alan Turing, whose universal computing engine foreshadowed the logical structure of modern digital computers; J. B. S. Haldane, geneticist, population statistician and Marxist writer; physicist Erwin Schrödinger, whose interests included molecular biology, the foundations of physics, philosophy and Eastern religious thought; and Ludwig Wittgenstein, the "influential philosopher of this century." Their task is to advise an anxious British government as to whether or not the new computers coming on the scene after World War II can "think." To answer this question, they first introduce the concept of a universal computer and describe the ways in which its functions compare to those of a human brain. They discuss what it means to think, the relationship of thought to communication and the ability to sense the environment, and how thinking might be a distinguishing human characteristic.

After describing the participants, the book's prologue introduces the central theme: Can computers think? Chapter 1, "The Sherry: An Evening at Christ's," sets the scene and introduces the five diners. Chapter 2, "The Soup: Brains and Machines," summarizes universal computing machines, Gödel incompleteness, solvability and computability. Chapter 3, "The Fish: Minds and Machines," introduces Turing's answer to the question, How do we know another being is thinking? Chapter 4, "The Meat: Meaning and Machines," questions whether syntax implies semantics. Chapter 5, "The Salad: Language and Thought," explores the questions, What is language? and Is it necessary for thought? Chapter 6, "The Dessert: Life and Personhood," asks, What is a person? Then

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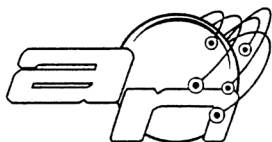
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