IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Michael Polis or Zongli Lin, associate editors for book reviews.

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Guesstimation: Solving the World's Problems on the Back of a Cocktail Napkin

by LAWRENCE WEINSTEIN and JOHN A. ADAMS
Reviewed by Gary H. Bernstein

My brother—the editor of this magazine—and I have spent more than one long afternoon challenging each other to estimate various things, such as the number of bacteria on Earth. The only requirement for this "game" is that the challenger must have an idea of the answer based on some reference source, which presumably is based on the estimates of someone more knowledgeable than either of us. Out of this game arose the idea that someone, maybe us, should write a book on estimating as a kind of useful art. Like most ideas for projects, we never got around to it, but happily, someone else did. That book is *Guesstimation—Solving the World's Problems on the Back of a Cocktail Napkin*, by Lawrence Weinstein and John A. Adams, both of Old Dominion University.

In teaching a course on semiconductor materials, I usually start off the semester by asking the students to compare the number of grains of sand on all the beaches on Earth to the number of atoms in a single grain of sand. To do this, several assumptions must be made. For example, we might ask what constitutes a beach? How much land mass should we account for? Do we include lakes? How can we know the precise length of the land or ocean interfaces on all of the continents, and, if we could, how much of that is beaches? How deep do we go down into the beach, and how far inland does the beach extend? How large is a grain of sand? What are the atomic size scales in a hypothetical grain of sand? To get started, I somewhat arbitrarily choose a "beach" to be 1-m deep and 20-m wide. Also, I roughly suppose that North and South America combined have 50,000 km of beaches, and I multiply that by five to account for the rest of the world. I keep my estimates to multiples of 1, 2, 5, and 10 to make the mental math easier. Decimal points and the numbers 3, 4, 6, 7, 8, and 9 are forbidden, although I keep track of exponents, which can be any integer.

I also imagine, without experimentation, that a grain of sand is about half of a millimeter wide, is cubical, and, as a rough guess for a generalized mineral, has atoms at about 2-angstrom centers. Taking all of this estimation into account, I obtain the value of about 10^{19} for both the grains of sand on the beaches and atoms in a grain of sand. Of course, alternative assumptions lead to different results, but for my purposes this set of assumptions, or any similar set, is sufficient to show that atoms are quite small. This example also helps make the point that semiconductor devices on the nanoscale are impressively small. Through this estimation, I hope that the students gain some appreciation for the scales in which they will be working for the semester.

This pastime also helps to put numbers in perspective in other ways. For example, it is variously estimated that the number of subatomic particles in the universe is about 10^{80}, which can be arrived at by knowing a few basic cosmological facts, including the estimated size of the universe, the number of particles floating around in deep space, the number of stars in a galaxy, and the number of galaxies in the universe. It turns out that either using the material between the stars or using the stars themselves for this estimate gives about the same answer, but a factor of two or so does not change the answer in a meaningful way. The important lesson here is to gain a sense of large numbers as the exponent increases gradually and to note that small changes to exponents make a big difference to the answer. Students without a good feel for the effect of exponents typically guess that the number of grains of sand on the Earth's beaches is 10^{100} or 10^{1000}. These guesses point out a lack of feel for large numbers, which play an important role in a basic semiconductors class.

THE BOOK

According to Wikipedia, the noun "guesstimate" originated in the 1930s, and the Merriam-Webster dictionary defines it as an "an estimate usually made without adequate information." In their book, Weinstein and Adams elevate the skill of guesstimation to an art form. Their approach helps the reader to appreciate and engage in this useful activity. The book is written at a level appropriate for nontechnical readers and is an easy read. Although one might think that the concept could become dry over time, in fact it is like eating potato chips—you can't eat just one. Page after page flies by as the reader is challenged to compare his or her assumptions with those of the authors. The book is broken into topics such as "Transportation," "Energy and

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Work," and "Energy and the Environment," where each problem, or vignette, involves one to two pages of analysis followed by the guesstimate and a short discussion, which often compares the guesstimate to known facts. Some of the problems are like the grains of sand example, where the answer is not precisely known, for instance, how many cells are there in the human body, but others have answers that can be checked by hard data, such as how much electrical energy the United States or Europe uses.

The authors skillfully and gently lead the reader through a process of analysis by estimation intended to teach how to break a problem down into small pieces and then arrive at a reasonably accurate, within an order of magnitude, conclusion that helps draw useful conclusions. One particularly interesting vignette analyzes the relative benefits of using baby carriers on airline seats. The conclusion drawn through guesstimating is that the cost of an extra airline seat likely forces some parents to choose to drive rather than fly, which makes traveling for them considerably more dangerous than flying. Therefore, the use of baby carriers on an airplane likely has a cost in terms of total lives put at risk. Other sections address current energy concerns, such as a comparison of the number of batteries needed for electric cars to replace gasoline, the energy output of humans, and how much land would be needed to switch over to ethanol for all of our cars.

At the beginning of each problem, hints are provided in small inverted text so that if you don't know how to begin you can peek and use information that helps you move forward. In some cases, I wondered whether or not the authors benefitted from hindsight to help their "guessing," but in the end the answers are intriguing enough to warrant the reader's attention. Since the book provides all of the arithmetic, it is easy to go through each problem posed and then ponder the significance of the outcomes. In addition, the authors scatter humorous spice throughout, many instances of which are LOL funny. These nuggets are interspersed at a sufficient density to draw the reader forward. Personally, I wondered when I was going to get tired of more examples of guesstimating, but I found myself continually drawn to the next problem. When I started, I fully expected not to finish the entire book, but that turned out to be a bad guess. Although some of the problems posed are trivial, as the authors admit from the outset, most are thought provoking, and many help place current social and environmental problems into technically meaningful perspective.

CONCLUSIONS

By the end of the book, the reader has seen enough examples to have the confidence to take on even the most daunting guesstimating challenges. I was already primed to accept the premise of the book, but I venture that students will also find it interesting and enlightening. My personal experience with the U.S. public school curriculum is that K–6 students are presented with estimation problems, but this skill is not developed in middle and high schools. This book should be in every high school library, if not on every high school reading list, and offered as part of introductory science and engineering curricula. I would guesstimate that even seasoned engineers will find the book thoroughly enjoyable.

The point of this book is not merely to provide answers, but rather to empower the reader with the ability to start from limited factual knowledge and ultimately arrive at useful conclusions using a few basic techniques. It is well supported by the book that guesstimating is an important skill for all engineers and scientists. Personally, I feel that being a good guesstimator is akin to having a firm grasp on the realities of life. Whether or not the ability to guesstimate well is related to "success" in life is a topic for future investigation by social scientists.

REVIEWER INFORMATION

Gary H. Bernstein received the Ph.D. from Arizona State University in 1987. He joined the Department of Electrical Engineering at the University of Notre Dame in 1988, where he founded the Notre Dame Nanoelectronics Facility. He received an NSF Presidential Faculty Fellowship in 1992. His research interests include electron beam lithography, high-speed integrated circuits, electromigration, MEMS, and electronics packaging.

Classical Success

Tsien also referred his engineers to the appropriate reference materials. His book *Engineering Cybernetics*, for instance, was a valuable guide for engineers in redefining the DF2. Particularly important was Tsien's interpretation of the Bliss formula, based on the work of a mathematician best known for his work on the calculus of variations and for the application of calculus to the field of ballistics during World War II. In *Engineering Cybernetics*, Tsien applied Bliss's work to the science of guided missiles, and his application was later exploited by Chinese engineers to design a simple guidance system for the new, improved DF2. Chinese aeronautical engineers claim today that Tsiens' book helped provide a sound theoretical foundation for an entire generation of Chinese rockets: from the DF2 to the DF5.

—*Thread of the Silkworm*, by Iris Chang, BasicBooks, New York, 1994, pp. 220–221.