Is computing equivalent to knowing?

Information, Uncertainty, Complexity

J. F. Traub, G. W. Wasilkowski, H. Wozniakowski

176 pp. Addison–Wesley, Reading, Massachusetts, 1983. $34.85

Reviewed by John J. Bartholdi III and Joseph Ford

Computational complexity is now an area of intensely active research in the computer science and mathematics communities. It is the study of the computational resources required to answer a question or, indeed, to determine whether the question is answerable at all. The issues of computational complexity are those of a sort of operational epistemology: What can we know? What resources are required to know it? And especially, how soon can we know it? Here questions are limited to those about formal systems, models and so on, so that "knowing" is equivalent to "computing."

Physicists should be interested in these issues, for they may determine whether a physical theory is operationally useful. However, this book is probably not the one by which to introduce oneself to the subject. It is a research monograph, subject to all the attendant limitations: The material is unsettled and exploratory, and the presentation uneven. The exposition is not polished but displays all the attributes of a large work in process. There is not much interpreting of the material; the many examples have more the flavor of arguments justifying the theory than of illustrations.

In fact, this book is the first of two that improve and extend an earlier work by two of the same authors, *A General Theory of Optimal Algorithms*, by Traub and Wozniakowski (Academic, New York, 1980). Many of the same examples are reanalyzed here, except now under a new and more elegant theory. Annoyingly, one frequently cited example uses the incompatible notation of the previous book.

Despite these faults, this book may be of interest to physicists because its contribution is to expand the notion of what a problem is. In complexity theory computer scientists tend to think of "the problem" as the formalized statement of input to a computational process. Traub and his coauthors explicitly recognize that the computer input is only an imperfect representation of the "real" problem. They postulate an information operator that partitions the class of problems into equivalence classes: All problems in the same equivalence class appear identical under the information available. Thus each equivalence class may be represented by a canonical problem, which is a model or approximation of all the problems in the class. It is on this canonical problem that our solution algorithm operates to produce an answer.

Most of complexity theory deals with how well the canonical problem can be solved, and at what cost. The authors study the more fundamental question of how accurately the real problem is solved when we solve only the canonical problem. Typically this involves determining the best guarantee of accuracy that can be made for any conceivable algorithm; not surprisingly, this depends on the structure of the information operator. Several forms of this question are treated, depending on

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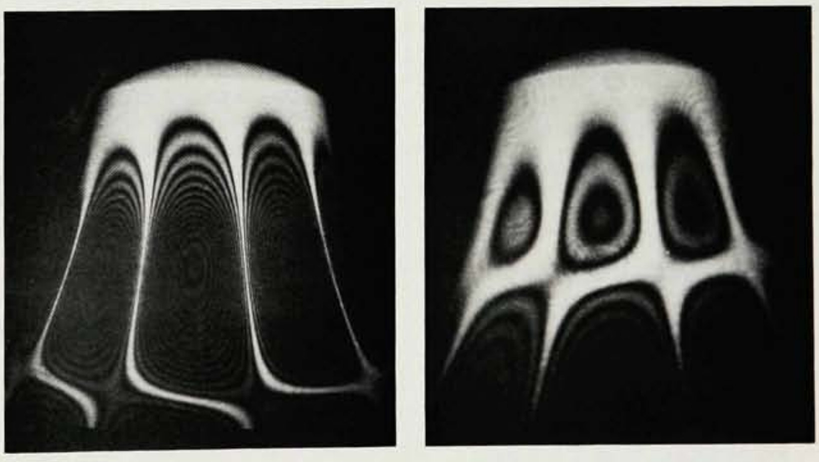

Holographic interferograms of the (6,0) mode at 1200 Hz (left) and the (6,1) mode at 991 Hz (right) in a handbell. The holograms clearly show the pattern of nodes and antinodes of the standing waves and help to define the complex series of partials that make up the sound produced by a struck bell. These holograms are published in *Acoustics of Bells*, edited by Thomas D. Rossing (Van Nostrand Reinhold, New York, 1984). The book, one of the volumes of the "Benchmark Papers in Acoustics" series, is a collection of reprints of papers and articles covering the period of the last 95 years. The first section, "Early investigations," contains an article by Lord Rayleigh, first published in 1890, describing his acoustical investigations of bells, conducted during the period 1879–90. The other sections of the book contain articles on various aspects of bell acoustics, founding and tuning; types of bells treated include chimes, tubular bells, electronic carillons and handbells. The book gives an overview of a complex science that originated with the artisanal skills of bell founders in the Middle Ages. (Photo courtesy of Richard W. Peterson.)

whether information is exact, partial or approximate. All assessments are in terms of the worst-case error (for example, what is the smallest worst-case error bound that can be established?). The next volume promises to treat the issues of expected error.

The authors have introduced an especially useful concept, the "radius of information": a measure of how well an information operator partitions the space of problems. Ideally, problems that have very similar solutions look alike under our information, that is, they are in the same equivalence class. The "best" information operator would separate the class of problems in a way consistent with the structure of the problems; it would give "more information" (more equivalence classes) only where it is important to make distinctions, such as when similar problems have very different solutions. The radius of information limits the accuracy with which the problems of an equivalence class are solved by the solution to the canonical problem. Thus a small radius of information means that the canonical problems of an information operator are faithful representatives of the real problems of their corresponding equivalence classes.

This theory is very broad and unifying, and usefully formalizes issues of which we may have been but dimly aware. While the book does not explicitly discuss modeling, we found it suggestive in relating formal issues of complexity and approximation to the less formalized art of modeling, by showing precisely how the information summarized in a model inherently limits the accuracy of possible solutions. The results of this theory are large, descriptive and organizational. There are no surprises and no sharp, specific tools yet, but this theory offers a unifying view that allows the mind to think more freely.

The Experience of Science: An Interdisciplinary Approach

M. Goldstein and I. Goldstein
400 pp. Plenum Press, New York, 1984. $22.50

Critics of higher education in the United States are once again up in arms against a trend that has persisted for most of this century. As the requirements of professional education become more stringent and formal, "liberal" education gets eased out of the curriculum. This means we are turning out students with a pitiful scientific preparation for citizenship in a technologically advanced democracy.

Few observers of the educational scene would dare to challenge this assessment. The question, as always, is what to do about it. This book makes a novel attempt to meet the problem head on.

In brief, *The Experience of Science* treats science as a process rather than as a body of knowledge. It is designed to acquaint students with the methods, goals and achievements of scientific inquiry. It does this by direct exposition and through careful analysis of three case studies from different branches of science.

If the book has one central theme, it is that facts can be slippery creatures. They can hardly avoid being "theory-laden," they may be biased or insufficiently precise, and they are easily misinterpreted. Though endorsing Karl Popper's "falsifiability" as the litmus test of what is worthy to be called "science," the Goldsteins are careful to emphasize the difficulty of deciding whether a particular negative result represents a fatal blow to a theory.

There is also a serious effort to elevate the student's mathematical sophistication by showing how scientists employ mathematics in ways quite foreign to the common experience. One striking example is Leonhard Euler's analysis of the puzzle of the Königsberg Bridges, a demonstration of nonquantitative uses of mathematical reasoning. Several chapters are devoted to probability and statistics, especially as used in the design and analysis of experiments.

The best case study concerns the controversy over the nature of heat. It shows convincingly why the caloric theory, which in retrospect would appear to have suffered a death-blow from the experiments of Count Rumford, nonetheless hung on for 40 more years. It took James Prescott Joule's precise work on the mechanical equivalent of heat to give most physicists and chemists sufficient reason to embrace the new model, and the whole of the energy paradigm as well.

The same cannot be said, unfortunately, for a study on the problem of mental illness, especially schizophrenia. This phenomenon, and the professions, institutions and conceptual structures that have been developed to deal with it, hardly represent a shining chapter in the saga of science. Though the authors use it as a vehicle for teaching a good deal of biology, the student is likely to feel cast into a bog in which there is no solid ground. Though the message perhaps needs to be delivered, the presentation may sow too much confusion to be of pedagogic value.

The third case study concerns John Snow's unraveling of the epidemiology of cholera. It is a fine scientific detective story, emphasizing the difficulty of