Book Review

David C. Krakauer
Santa Fe Institute
1399 Hyde Park Road
Santa Fe, NM 87501
krakauer@santafe.edu

Information and its Role in Nature. J. G. Roederer. (2005, Springer.) Hardcover, $59.95, 235 pages. ISBN 3-540-23075-0.

With the growth of the Internet, the concomitant movement of the market towards server-based vendors and efficient search engines, and the advent of high-throughput scientific methods promoting easy access to data, the storage, acquisition, and analysis of information have become some of the dominant concerns of our time. Whereas previous centuries witnessed the ascendancy of machines and built upon them mechanical theories of the universe and society, our own century has looked towards information as a fundamental metaphor for organizing science and civilization. It remains surprising therefore that no generally accepted definition of information exists, beyond that provided by Claude Shannon in 1949, whose original domain of application was somewhat limited to communication problems in engineering.

Over the last twenty years several important articles and books have been published that seek to move information beyond a mere statistical measure of communication or uncertainty assaying underlying physical properties, to a position where information is treated as a part of more general complexity measures related to computational work. Physical mechanisms are considered in tandem with information, providing essential substrates and constraints on information such that only by placing matter, energy, and information on an equal footing can we hope to understand the true nature of adaptive decision making mechanisms. In addition to promoting informational sciences, this has also proven to be a program in interdisciplinary thinking, as new bridges have needed to be built between the biological, physical, and mathematical disciplines in order to fully understand their correspondences.

It is in this spirit of information as a fundamental organizing principle in physical nature, and in particular adaptive nature, that Juan G. Roederer has written his book: *Information and its role in nature.* This is in many ways a curious book, and it is not precisely clear who the target audience is. The book is organized into six chapters (and 235 pages) on classical information theory, quantum information theory, physical interactions, the role of information in biology, the role of information in physics (described as passive), and information and the brain. The titles of the chapters provide only a clue to their contents which span the origin of the universe and the emergence of consciousness. Information in the technical sense plays only a small role in any of the chapters, and greater emphasis is placed on physical or adaptive correlations among components of a system, which we would more typically associate with complexity measures. The chapters with a physics emphasis tend to be stronger than those in biology.

As I have suggested previously, the book does not provide enough detail on information theory to be useful as an introduction to the field or as a reference, and it omits altogether discussion of relative entropy, mutual information, channel coding, and network information, concepts that would have served the author's interest in causality. The book spends a fair amount of time discussing quantum mechanics and touches on quantum information theory, but not broadly enough to provide significant utility for students of the field. The book also chooses not to discuss the physics of computation, as researched by Landauer, Bennet, and their colleagues. The book feels more like a personal odyssey through a variety of areas of great interest, loosely connected by qualitative information concepts, and is perhaps best suited to those who have already navigated through similar territories.

There are some excellent books in information theory and its applications available to those interested in the field. At the more technical end of the spectrum I would cite Cover and Thomas, *Elements of information theory*, as the canonical text. For those interested in information, learning, and generalization, Mackay's book, *Information theory, inference and learning algorithms* is excellent. Nielsen and Chuang's monograph on *Quantum computation and quantum information* is the best introduction to the quantum physics of information processing. The best book on the information theory of neural systems remains *Spikes*, coauthored by Rieke, Warland, deRuyter, and Bialek. The least formal popular account of the whole field is provided by von Bayer in his book *Information, the new language of science*.

This book I would place somewhere near the center of intellectual mass of these prior publications, leaning towards the more technical but without enough detail to be useful as a textbook. But this evaluation would not provide a sufficient triangulation of its contents, as its most persistent feature, setting it somewhat aside from those books, is that it presents the hypothesis that information is the defining feature of adaptive systems, like the nervous system and the genome, and that it is not Shannon's formulation that we need in order to understand life, but a *pragmatic information* concept that captures semantic or functional properties of communication. In this respect it is more closely allied to books like David Layzer's *Cosmogenesis* and Seth Lloyd's more recent *Programming the universe*. Like Layzer's and Lloyd's books, in addition to providing background on cosmology, computation, and information, it endeavors to provide a conceptual framework based on the concept of information to organize a range of physical phenomena. However, as with Layzer's and Lloyd's books, you might not agree with the thesis.

The core thesis of the book is the idea of "interaction as an epistemological primitive" and "information driven interactions" as opposed to force-driven interactions. In this scheme information serves to modify system behavior in a purposeful way. Purpose is a teleonomic concept and, as Roederer explains, requires that we specify the function of the information. The absence of an explicit functional or consequential character to information has been an enduring criticism of Shannon's formulation since its presentation in 1949 in his long article "A mathematical theory of communication," published in Vol. 47 of *The Bell System Technical Journal*. I think it worthwhile to quote Shannon's intentions as he stated them on the first page in the second paragraph of his article:

> The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have *meaning*; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one *selected from a set* of possible messages. The system must be designed to operate for each possible selection, not just the one which will actually be chosen since this is unknown at the time of design.

The whole of information theory as we know it today, is derived from the premise that the *meaning* of the message is not relevant to the *engineering* problem. As Shannon implied, the set of possible meanings must be known by both parties in advance of the communication event. In the book *The mathematical theory of communication* jointly edited by Shannon and Weaver, Shannon presented a lightly edited copy of his original Bell journal article, whereas Weaver contributed a second section on "Recent contributions to the mathematical theory of communication." In that section Weaver introduced the three levels of a communication problem:

- *Level A.* How accurately can the symbols of communication be transmitted? (The technical problem.)
- *Level B.* How precisely do the transmitted symbols convey the desired meaning? (The semantic problem.)

- *Level C.* How effectively does the received meaning affect conduct in the desired way? (The effectivity problem.)

Shannon's theory is ostensibly restricted to level A. However, Weaver then proceeds to explore the many ways in which the concerns of level A have an influence on levels B and C. The critical point that Weaver makes is that there would be little hope of any insight into levels B and C if we had not first clearly defined the problems of level A.

Weaver's section concludes with a quotation from Eddington's book *The nature of the physical world*: "Suppose we were asked to arrange the following in two categories—*distance, mass, electric force, entropy, beauty, melody*. I think there are the strongest grounds for placing entropy alongside beauty and melody, and not the first three." Eddington suggests that entropy has found itself in the company of physical measures simply because it is similarly expressed in the language of arithmetic. The profound insight here is that entropy contains both an objective and a subjective component by virtue of the arbitrary process of coarse-graining into symbols and their associated probability distributions.

Roederer's answer to the subjectivity of entropy and missing levels B and C, is to emphasize the concept of *pragmatic information*, which he defines as "that which represents the univocal correspondence between the pattern and the evoked change" (p. 121). "Univocal" is defined as "having only one meaning." This leaves us with a rather confusing concept, which, on substitution of the definition, reads: that which represents a single-meaning correspondence between the patterns and evoked change. I read this as a deterministic change in the behavior of a receiver when presented with a pattern by a sender—in other words, some composite of levels B and C. Speaking for myself, I do not find this definition more clear than that provided by Weaver. In fact, this definition on its own, without the additional qualifications made in the text, is open to exactly the kind of interpretation that Roederer is so keen to avoid—information as a purely physical interaction analogous to a force.

Throughout the book, ideas relating to statistical complexity measures such as algorithmic depth recur. These are used both to expose the limitations of the pure entropy definitions of complexity—which assign maximum complexity to random sequences—and also to explicate scientific theory, which seeks to explain the maximum empirical diversity among observables by making use of highly compressed expressions, describing the regular dependences among the variables. These are interesting digressions, but they are not adequately stitched into the body of the text, and so it remains unstated how they relate to the core emphasis on a non-quantitative, pragmatic theory of information.

In conclusion, it is fair to say that a great number of ideas have found their way into this book—the scope of interests spans field theory, genetics, and neuroscience. I think these ideas are central to our understanding of the adaptive portion of the universe. But out of frustration with the limits of formal information theory, Roederer has sought to bind these ideas together using a qualitative concept of information based on evolved or learned associations describing signaler-induced changes in the state of a receiver. Speaking for myself, I do not think this concept resolves many problems. However, the effort at synthesis is interesting and redefines an important vector we need to remain aware of in the space of scientific research.