two quite different forms of cognitive growth in the individual.

The distinction Rogoff makes between skill development and shifts in perspective is only beginning to be explicated in studies of children's cognitive development, and it remains problematic in certain respects. However, along with several of the other constructs and distinctions Rogoff has outlined in this volume, it goes a long way toward clarifying central debates in the field, and it is one of the points that makes this the best account of a sociocultural approach to cognitive development we have to date.

JAMES V. WERTSH
Frances L. Hiatt School of Psychology, Clark University, Worcester, MA 01610-1477
PETER TULVISTE
Department of Psychology, Tartu University, Tartu, Estonia.

The Mind's Eye

Principles of Mental Imagery. RONALD A. FINKE. MIT Press, Cambridge, MA, 1990. x, 179 pp., illus. $19.95.

Mental Imagery. On the Limits of Cognitive Science. MARK ROLLINS. Yale University Press, New Haven, CT, 1989. xx, 170 pp. $21.50.

Mental imagery is a topic that has long engaged psychologists and philosophers. Reasons for this range from the practical (ancient Greeks developed imagery-based strategies for facilitating memory) to the creative (Kekulé is reputed to have discovered the molecular structure of benzene by imagining a ring of snakes). Thus, it is not surprising that the reemergence of representation-based psychology under the guise of cognitive science was sparked in part by new discoveries on imagery (most notably by Roger Shepard and his coworkers). These findings brought with them new concerns about the status of visual imagery as a distinct representational medium and, consequently, during the late '70s, imagery became the focal point of an extended debate on the nature of the internal representations of the mind. Just as cognitive science is an interdisciplinary endeavor, so the imagery debate began as an interdisciplinary rift with lines drawn by discipline. On one side were the descriptionalists, mostly philosophers, who argued that cognition is the product of propositionally based, non-visual representations—a so-called "language of thought". On the other side were the pictorialists, mostly experimental psychologists who argued that a complete theory of cognition must also include pictorial representations as distinct entities to account for new findings concerning visual imagery.

In this context, it is remarkable that two books about imagery, one by an experimental psychologist and one by a philosopher, could lead the reader to similar conclusions. The agreement is even more striking in view of their radically different approaches. Finke, one of the more ingenious experimentalists studying imagery today, ignores most philosophical arguments, overwhelming the reader with an onslaught of data supporting the pictorial conception of imagery. In contrast, Rollins, the philosopher, ignores most empirical findings concerning imagery, leading the reader through a series of carefully reasoned logical arguments likewise supporting the pictorial viewpoint.

This agreement is more than superficial. Both authors attempt to demonstrate the viability of their particular visions of mental imagery as a pictorial medium. Unfortunately, neither is willing to commit himself to a precise mechanistic theory of mental imagery. In Rollins's case this is less surprising; as a philosopher he is more concerned with what is hypothetically plausible than with what must be explained by theory. To this end, Rollins makes it clear that his goal is to establish "that mental depiction plays a role in cognition that is different than that of mental description" (p. xvi). Yet I was disturbed by the small number of references to the empirical. This is fine if one is concerned only about representation in the abstract, but if one is concerned with the human capacity for imagery then existing behavioral data must be addressed (given the unexpected solutions the human brain has adopted via natural selection). Furthermore, Rollins's claim that "pictorialists have not probed the representational properties of displays or depictions sufficiently to produce a fully developed theory" (p. xiv) is unwarranted given his disregard for the significant theoretical progress made over the past decade (for instance, the work of David Marr or Irving Biederman). This same omission is less forgivable in Finke's book, where only a few pages are devoted to recent advances in visual representation. Instead Finke concentrates on five "general principles of mental imagery" that elucidate broad rules for how pictorial representations should function. Finke defends this position by arguing that principles avoid many of the "disadvantages" of using computational models, yet still "identify the general characteristics of a cognitive process that are common to many tasks" (p. 144). Though this may be true, I disagree with his dismissal of formal models. As in any science, adequate theories of the mind must ultimately specify the precise mechanisms and representations underlying cognition.

Both authors concentrate on areas they know best. Together the two monographs make an excellent introduction to the central elements of the imagery debate—Finke providing an exhaustive review of the collected knowledge about the human capacity for imagery and Rollins providing a thoughtful discussion of the philosophical questions. My guess is that each will also find its own niche in the literature: Finke's volume serving as a concise yet comprehensive reference work and Rollins's volume providing a model case study of the broader issues surrounding the nature of mental representation. However, since much of what they omit will in all likelihood form the core of a theory of visual representation, their works are already somewhat out of date.

MICHAEL J. TARR
Department of Psychology, Yale University, New Haven, CT 06520

Atomic Clocks

The Quantum Physics of Atomic Frequency Standards. JACQUES VANIER and CLAUDE AUDOIN. Hilger, Philadelphia, 1989 (distributor, American Institute of Physics, New York). Two volumes, boxed. xviii, 1567 pp., illus. $550.

Atomic frequency standards are electronic devices by means of which the frequency of oscillation of an electromagnetic wave associated with the transition of an atom from one energy state to another is made available as the basis for an extremely uniform or accurate time scale. Such devices are the "atomic clocks" properly so called, as they function, quite analogously to pendulum clocks and quartz crystal timekeepers, by repetitively marking off and adding up very nearly equal time intervals. By contrast, radiocarbon dating and other such methods put only approximate dates on particular artifacts by estimating the degree of relaxation of a population of nuclei or atoms from some higher energy state.

Atomic frequency standards are available as commercial instruments, neatly packaged and pictured in electronic manufacturers' catalogs, or they may be found as specially built-up apparatus in a few dozen time-standard development laboratories around the world. Between these two extremes lies a wide range and large number of made-to-order devices—usually excelling through diminishment of their size, weight, or sensitivity to their physical environment—for various military, national security, and space applications.

First rendered practicable by the advances in electronic and microwave techniques during World War II, atomic frequency standards of several types were developed in the following two decades. By 1967 it had become feasible to shift the definition of the second, through international agreement, from an astronomical to an atomic basis. Indeed, by that date and ever since, the precision attainable in frequency and time measurement through the improvement and proliferation of atomic clocks has far exceeded that attainable in the measurement of any other physical quantity. Consequently, other quantities (meter, volt, ohm) are increasingly redefined, by international agreement, in terms of frequency.

The interdependence of basic physics and atomic frequency standards was attested late last year by the Swedish Academy of Sciences in dividing the 1989 Nobel Prize for Physics between Norman Ramsey, "for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic clocks," and Hans Dehmelt and Wolfgang Paul "for the development of the ion trap technique," which technique underlies the newest and most promising approach to making still better atomic clocks. The complex interdependence of atomic clock work and the advance of basic physics is not depreciated but further displayed if we note that, the Nobel Committee for Physics notwithstanding, the method of separated oscillatory fields, which Ramsey conceived in 1948 and which found immediate application in the cesium atomic beam clock—long the most accurate as well as the most widely employed type of atomic clock—is in fact not used in the hydrogen maser. As Vanier and Audoin appropriately and perceptively emphasize, this latter device, which Ramsey invented in 1960 in collaboration with his student Daniel Kleppner, relies, rather, on a principle conceived by Robert Dicke for the same purpose as Ramsey's method of separated oscillatory fields, namely reducing the frequency spread of atomic transitions—and, moreover, conceived by Dicke with its application to an atomic clock clearly in mind.

In general, the connections between basic physics and atomic clockwork prized by the Nobel Committee are nowhere developed in greater depth and detail than in Vanier and Audoin's treatise. The authors, who have for many years headed two of the very few atomic frequency standard development laboratories that have programs of graduate instruction, have evidently elaborated this treatise out of courses of lectures for students with a background in electrical engineering. Presupposing some grasp of the electronic systems, functions, and hardware, by means of which these devices operate *as* devices, Vanier and Audoin provide their readers with all the physical theory—from the Bohr atom on up—necessary to understand what, physically, is going on in the atom-filled hearts of these devices and to analyze the limits on the accuracy and stability of their operation imposed by that physics.

This conception of audience and function reflects the demography of the field of atomic clock development and application: the overwhelming majority of those working in the field are electrical engineers concerned with the electronics that make the clocks work and with the systems into which these working devices are integrated. Even the majority of that small minority concerned with "the physics package" come from electrical engineering. Yet Vanier and Audoin's treatise covers its subject so comprehensively, so connects physical theory and atomic clock technology, that it will be as indispensable to the expert as to the novice.

PAUL FORMAN
National Museum of American History, Washington, DC 20560, and Department of Physics, New York University, New York, NY 10003

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