traits has arisen and to compare the success of these lineages with that of their sister groups. The relevant phylogenetic tests have not been carried out, but it seems quite possible that the army ant groups are no more successful, with respect to net diversification (that is, contemporary species richness), than their generalist sister groups. If success is measured in terms of ecological dominance, then the true army ants are demonstrably important in many tropical and subtropical habitats, but the other groups—the army ant "wannabes"—are more limited in distribution, diversity, and abundance, and their ecological significance remains unclear.

The book concludes with an appeal for increased efforts toward conservation of tropical ecosystems where most army ant species—and biological diversity in general—reside. Despite their large colony sizes and seeming invincibility, army ants and their obligate symbionts are especially vulnerable to habitat fragmentation. This is because population (as opposed to colony) sizes are rather low and because the queens, as wingless individuals reproducing by colony fission, are very poor colonizers of isolated pieces of landscape. In reality, our rampages endanger army ants much more than their activities pose a threat to human life or limb.

Philip S. Ward
*Department of Entomology,
University of California,
Davis, CA 95616, USA*

The WAM Report

Dynamics and Modelling of Ocean Waves. G. J. KOMEN, L. CAVALERI, M. DONELAN, K. HASSELMANN, S. HASSELMANN, AND P. A. E. M. JANSSEN. Cambridge University Press, New York, 1994. xxii, 532 pp., illus. $59.95 or £40.

That water waves are generated by wind was known to the ancients and proclaimed by such polymaths as Leonardo da Vinci and Benjamin Franklin, but scientific prediction of these phenomena has been attempted only in the past 50 years. The complete problem comprises two, essentially distinct parts: the prediction of the wind field, which is the province of meteorologists, and the prediction of the resulting response of the ocean surface, which is the province of oceanographers. The present monograph, which appears as the final report of the WAM (Wave Modelling) group, provides a state-of-the-art survey of the latter problem. The title page lists six authors, but 35 scientists from 12 nations are listed as "contributors" and the WAM-group list comprises 71 individuals. This is manifestly an international effort.

The first predictive model, developed by Sverdrup and Munk (1943–1947) in response to the need for sea and swell forecasts for the Allied invasion of North Africa, was based on empirical relations between characteristic parameters of the wave and wind fields and antedated the statistical description of the problem by Pierson, Neumann, and James in 1955. The starting point for subsequent models, including those covered in the volume under review, is the Boltzmann-like transport equation.

$$\frac{\partial F}{\partial t} + \mathbf{v} \cdot \nabla F = S_{in} + S_{nl} + S_{ds},$$

which governs the evolution of the surface-wave field in space ($\mathbf{x}$) and time (t); $F = F(f, \theta; \mathbf{x}, t)$ is the two-dimensional spectral density in frequency f and direction of propagation θ, $\mathbf{v} = \mathbf{v}\ (f, \theta)$ is the group velocity, S_{in} is the input from the wind, S_{nl} is the nonlinear transfer through wave interactions, and S_{ds} is the dissipation. This approach became practical only in the early 1960s with the theoretical studies of Phillips (1957) and Miles (1957), which provided a basis for the representation of S_{in}, and the discovery of resonant interactions by Hasselmann (1960) and Phillips (1960), which provided the basis for the representation of S_{nl}; the representation of S_{ds} was, and remains, empirical, with turbulence as an ineluctable antagonist.

Models based on the equation given above have been described as first-, second-, or third-generation, in which nonlinear interactions are, respectively, neglected, described in simplified parametric form, or incorporated within the limits of current knowledge and computing power. First-generation models failed to describe the nonlinear transfer of energy from higher frequencies, where wind generation is more efficient, to lower frequencies, where dissipation is weaker, and yielded rather misleading results. Second-generation models, which incorporated these effects, although not always successfully, were described in *Ocean Wave Modeling* by the SWAMP (SeaWave Modelling Project) Group, which I reviewed in *Science* (**229,** 377) in 1985 with the conclusion that "Future ('third generation') models, already under development, will incorporate more sophisticated parameterizations of S_{nl} and may exploit our theoretical knowledge to its present limits, after which the lack of a rational model of dissipation and the effects of finite, variable depth are likely to present barriers to further progress."

The present volume fulfills that promise, and, although the barriers remain, they may now be better described as impediments. Moreover, whereas the SWAMP book was primarily a progress report on second-generation models, Komen *et al.* provide full expositions of the basic fluid dynamics, numerical modeling, and incorporation of global satellite measurements. The development is not seamless, but, considering the number of contributors, the principal authors have done an admirable job of assembling a coherent whole and of providing a firm base for the exploration of the many challenging problems that remain.

John Miles
*Institute of Geophysics and
Planetary Physics,
University of California at San Diego,
La Jolla, CA 92093–0225, USA*

Visual Perception

Image and Brain. The Resolution of the Imagery Debate. STEPHEN M. KOSSLYN. MIT Press, Cambridge, MA, 1994. x, 516 pp., illus. $45 or £38.50.

Kosslyn's *Image and Brain* is a *tour de force* in the analysis of visual perception and imagery, looked upon from all possible perspectives. It is an examination of work done during the past 15 years on visual imagery by a variety of methods, from chronometric measurements to computer models to functional brain imaging, bringing a systematic approach to bear on this multitude of data to delineate the issues of brain mechanisms underlying visual perception and imagery. The scheme adopted posits a number of systems and subsystems (for example for edge detection and for encoding motion relations) that process specific kinds of information and that together make for an apparently seamless operation of visual perception and imagery. This analytical approach is open-ended, in the sense that more processing stations can be adduced if need or evidence for them arises; it is flexible, so that rearrangements in processing order are allowed for; and it is powerful, so that it can be applied rigorously to complex data. The net result is a coherent theory of visual perception and imagery in which results obtained by a diversity of methodologies—observations in normal and brain-damaged people, neuroimaging, neurophysiological experiments, and computer modeling—can be accommodated and used to explore and fill in gaps in our account of observed phenomena. This calculus of processes, as it were, that Kosslyn develops can be applied to diverse situations. An excellent example is its application to the case of a particular brain-damaged patient, as detailed on pages 276–282. The analysis here shows not only what the processing deficits may be in the patient but also what tests should be done to elucidate the situation. This brings home another point, namely that empirical findings can rarely be interpreted without a theoretical framework. *Image and Brain* offers a framework for making sense of hugely diverse data on visual perception and imagery that also leads to testable hypotheses and predictions, keeping it on solid evidential ground and enabling it to evolve as a more and more sophisticated instrument.

Thus the approach expounded in *Image and Brain* is a great analytical tool. But is this how the brain works? The explanation of a complex system's behavior rests heavily on the interaction of its components (W. Bechtel, *Can. J. Philos. Suppl.* **20**, 133 [1994]), and brains abound in contextually conditional states of affairs. Hence one can hardly give a global answer to this question; at best the answer can differ according to the particular processing system or systems involved.

Moreover, though the approach of *Image and Brain* has the merit of being rigorous and logical, the mechanisms used by the brain to actually solve a problem may not rely on a comparably logical series of steps. Specifically, I am referring to the possibility of "smart" mechanisms (S. Runeson, *Scand. J. Psychol.* **18**, 172 [1977]). An example is the polar planimeter, a physical device that can measure the area of an irregular shape without using any logical steps that one would ordinarily employ for that purpose, such as using a fine grid. If measuring an area were important for survival, it is possible that evolutionary pressure could have resulted in a neural operation that could likewise have been implemented by a neural network without following logical steps. Similar considerations hold for the motor system, where solutions to pressing problems could have been arrived at by a long evolutionary process of trial and error rather than by a succession of logical steps (A. P. Georgopoulos *et al.*, *Science* **237**, 301 [1987]). For example, movements of the arm involve movements of the joints, which are brought about by torques applied at the joints produced by contractions of muscles. To derive these torques, given the desired trajectory of hand in space, is a very tedious process of solving what is known as the inverse kinematics problem. Imagine the magnitude of this problem when, for example, the movement trajectories of four limbs have to be coordinated in time and space in a locomoting quadruped. And yet, the spinal cord can accomplish that feat alone. One can write down the logical steps in a series of box diagrams or in a mathematical solution of this problem, but from the fact that the problem is solved by the spinal cord it does not follow that it was solved in that particular way. It is much more plausible to suppose that the spinal cord has evolved as a neural network solving this problem without the benefit of mathematical or logical sequences. I believe that the answer to the question of how the brain actually does it lies somewhere in between, in that different processing subsystems may be involved in a given function but a number of them may implement "smart" mechanisms. But "smart" mechanisms are usually invented or discovered rather than arrived at by a logical process and therefore are much more difficult to find and identify. Keeping our eyes open is the smart thing to do.

As the book's title suggests, the theory developed in *Image and Brain* has far-reaching implications, with regard to the imagery debate. This debate during the 1970s and '80s focused on whether visual mental images are internally represented exclusively by language-like "propositional" representations or in part by "depictive" representations. In a depictive representation, shape is represented by points in a space: each point corresponds to a point on the object, and intervening points in the space correspond to intervening points on the object. The experimentally established fact that many cortical visual areas are topographically organized shows that the representations in these areas are depictive. Another recent finding is that "higher" visual areas have feedback connections to "lower," topographically organized areas. Therefore, it is reasonable to suppose, as Kosslyn proposes, that visual mental images are patterns of activation in topographically organized areas that are produced via these feedback connections. Evidence for shared mechanisms in imagery and perception is obviously relevant to the debate about the nature of images: if images share brain areas with perception, and these areas are hard-wired (that is, topographically organized) to represent shape depictively in perception, it follows that these areas represent shape depictively in imagery. This hypothesis is further supported by evidence that imagery not only activates homologous topographically organized areas in the human brain but is impaired when these areas are damaged. In summary, the central issue of the imagery debate can now be stated in concrete terms: do areas of the brain that depict visual information represent visual mental images? "Yes" is an educated answer. How are patterns of activation in these areas formed, manipulated, and used during imagery? With its schematic approach *Image and Brain* addresses these questions in a precise and challenging, yet enjoyable, way.

Apostolos P. Georgopoulos
Brain Sciences Center,
Veterans Affairs Medical Center,
Minneapolis, MN 55417, USA

Vignette: Proper Precautions

On the tiny dashboard monitor, they had a view looking straight down at the powerful body of a Tyrannosaurus rex, as it moved up the game trail toward them. Its skin was a mottled reddish brown, the color of dried blood. In dappled sunlight, they could clearly see the powerful muscles of its haunches. The animal moved quickly, without any sign of fear or hesitation.

Staring, Thorne said, "Everybody in the car."

—From *The Lost World*, a novel by Michael Crichton (Knopf)

Books Received

Aquaculture Development. Progress and Prospects. T. V. R. Pillay. Wiley, New York, 1994. x, 182 pp., illus. $59.95.

Behavioral Design. Nicholas S. Thompson, Ed. Plenum, New York, 1995. xvi, 334 pp., illus. $85. Perspectives in Ethology, vol. 11.

Publishers' Addresses

Below is information about how to direct orders for books reviewed in this issue. A fuller list of addresses of publishers represented in *Science* appears in the issue of 26 May 1995, page 1220.

Cambridge University Press, 110 Midland Ave., Port Chester, NY 10573–4930. Phone: 800-872-7423; 914-937-9600. Fax: 914-937-4712.

Comstock Press, P.O. Box 6525, Ithaca, NY 14851–6525. Phone: 800-666-2211 (outside NY state); 607-277-2211. Fax: 800-688-2877; 607-277-6292.

MIT Press, 55 Hayward St., Cambridge, MA 02142. Phone: 800-356-0343; 617-625-8569. Fax: 617-258-6779. E-mail: mitpress-orders@mit.edu.