

ful and detailed analysis of a small number of experimental paradigms that reveal the way in which attentional instructions can influence the speed and accuracy of visual recognition. For example, even a single letter presented in an otherwise empty visual field is identified faster and more accurately when it is preceded by a small dot in the same location. Apparently, access to the identity of visual shapes depends on access to their locations, and the dot enhances this localization process. These effects are small, however, because shapes that are not precued also activate attention "automatically" by virtue of their sudden onset. The cue merely provides a small head start for the attention mechanism.

Larger effects of attention can be observed when subjects are required to identify one letter embedded in a collection of similar letters. In this case, subjects derive a large advantage when the target is precued because there are no unique features such as sudden onset to indicate the position of the target. As Van der Heijden shows, however, the selection process is not perfect. Subjects sometimes substitute a nearby letter for the cued letter. A similar phenomenon, known as response competition, occurs when the cued object and a nearby object call for opposing motor responses. For example, subjects exhibit slow reaction times when they are attempting to name a red color patch flanked by the word "green." This interference is often reduced as the cue is presented at longer intervals but may not be eliminated. Response competition effects suggest that attentional selection of one object in the visual field does not preclude the identification of other, presumably unattended, objects.

Van der Heijden points out that, historically, theories of attention have entangled two questions that are actually independent of one another. First, should we conceive of the visual recognition system as being limited or unlimited in capacity? Second, does the selection of visual information occur "early" in the course of processing (prior to recognition) or "late"? Most models of attention are marked by a combination of limited capacity and early selection or unlimited capacity and late selection. Van der Heijden, however, suggests that a novel combination of early selection and unlimited capacity is required to account for the evidence. Early selection is implicated by the finding that subjects' judgments about the identity and location of a single letter are not independent. In particular, subjects rarely identify the letter if they failed to localize it. The precue improves performance by improving the location information. Thus, access to the identity of visual shapes is mediated through their locations.

The claim that visual recognition can be accomplished without capacity limits is supported by results, such as response competition, that show extensive analysis of forms outside the attended area. These results are consistent with the claim that all objects in the visual field are processed in parallel to an "identity level" where they may elicit partial activity in the response system. On this view, attentional selection of shapes is not required for them to escape the limits of visual recognition machinery but is needed for the subject to choose responses to them. Response systems are obviously "limited in capacity," and the author presents plausible arguments as to why selection based on location would provide useful information for the selection of responses.

Although the early-selection, unlimited-capacity model provides a nice account of some of the data, it fails to account for others. For example, although response competition effects sometimes occur for stimuli located far from the focus of attention, in other experiments these effects can be reduced or eliminated by providing a precue at a sufficient interval prior to the target. Second, there is accumulating evidence from single-unit recording experiments in monkeys as well as from event-related brain potentials in humans that unattended information is suppressed at early stages in visual recognition. These findings do not appear to be compatible with the parallel, unlimited-capacity assumption. Finally, this assumption appears to be contrary to a growing literature showing that visual recognition may require the combination of features such as color and shape through the mechanism of attention.

As Van der Heijden points out, "attention is an ambiguous and elusive concept." This book will help sharpen the debate on the nature of selective processes in vision.

James E. Hoffman

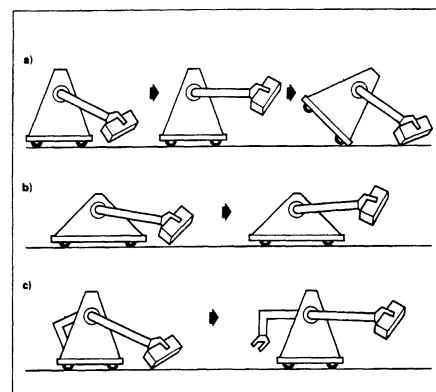
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Autonomous Systems

Intelligent Behavior in Animals and Robots. DAVID McFARLAND and THOMAS BÖSSER. MIT Press, Cambridge, MA, 1993. xiv, 308 pp., illus. \$39.95 or £35.95. Complex Adaptive Systems.

At least since Norbert Wiener's *Cybernetics* was published in 1948, and probably much earlier, there have been those who have believed that much might be gained from a common theoretical treatment of the be-



"Design problems associated with a brick-laying robot. (a) The robot is unstable once a brick is grasped. (b) Stability is achieved by altering the body shape at the expense of reduced height and increased weight. (c) Stability is achieved by the intelligent behavior of using the free arm as a counterweight." [From *Intelligent Behavior in Animals and Robots*]

havior of animals and certain machines. The modern incarnation of this tradition is a fast-growing body of research concerned with the adaptive behavior of so-called autonomous agents, a general class of systems of which animals and robots form important special cases. A basic tenet of this body of research is that the biologist trying to understand the mechanisms underlying animal behavior and the engineer seeking to build more versatile and robust robots can learn a great deal from one another.

Intelligent Behavior in Animals and Robots is one of the first book-length attempts to present a unified framework for this endeavor; it demonstrates clearly the progress that can be made by combining biological and engineering perspectives. McFarland and Bösser begin by arguing that intelligent behavior is behavior that is rational with respect to some criteria given particular peripheral capabilities and a particular environment. However, they carefully distinguish between rational behavior and the underlying mechanisms responsible for it, indeed questioning the assumption—common in traditional artificial intelligence research—that these mechanisms are necessarily cognitive.

Drawing heavily on experimental and theoretical work in ethology, the authors then go on to provide a theoretical framework in which both animals and robots are viewed as rational economic agents designed to maximize utility against cost. They are careful to point out that an animal cannot in general know the true utility or cost of taking a particular action in a particular environment. However, an animal can be designed through evolution in such a way as to optimize an estimate of this utility or cost, an estimate the authors call

a goal function. For animals, the utility or cost of a particular behavior is defined by its contribution to the animal's fitness, that is, the animal's subsequent survival and reproductive success. McFarland and Bösner argue that for robots, on the other hand, these notions should be defined in terms of the robot's commercial success in the marketplace. For example, in order to proliferate, a dishwashing robot must successfully compete with human dishwashers and existing automatic dishwashers in terms of cost, reliability, and quality of work. The book goes on to develop this similarity between commercial success and reproductive success into a formal analogy. Along the way, a number of other issues, such as the roles of motivation, goals, and learning in animals and robots, are also discussed.

A highlight of the book is a detailed illustration of the application of this general economic framework to the overall design of a housekeeping robot. Here the authors assume that a particular behavioral repertoire is given (for example, collecting dishes, mopping the floor, and so on) and the essential problem is to optimally deploy these behaviors in time while simultaneously considering issues of stability, reliability, and customer appeal. In general, the book tends to treat behaviors at a fairly high level, abstracting from details of the underlying mechanisms. In addition, the problem of selecting from a set of mutually incompatible alternatives is emphasized over the problem of fine-tuning ongoing behavior, though both are presumably crucial to an agent's success. Nevertheless, this simple example does clearly demonstrate the kind of analysis that the economic framework for intelligent behavior makes possible and illustrates how the results of such analysis can be used to guide the overall design of an autonomous robot.

Indeed, this book is at its best when drawing out the many strong analogies between animal and robot behavior and when presenting and illustrating the economic framework that is its central contribution. However, I think the book would have benefited from a clearer outline of its principal goals and overall plan at the outset. As it stands, the reader is left to sort through a number of seemingly tangential discussions and sometimes confusing terminology in order to grasp the essential ideas, a situation that the overly long lists of "points to remember" that end each chapter do little to alleviate. In addition, the minimal discussion of the large body of existing work on computer simulations of adaptive behavior and biologically inspired robotics is inadequate for this book to serve as a general introduction to the study of autonomous agents. Nevertheless, *Intelligent Behavior in Animals and Robots* stands as

an important first attempt at laying the groundwork for a unified treatment of the behavior of animals and robots. It sets the standard against which any future discussion of these issues must be judged.

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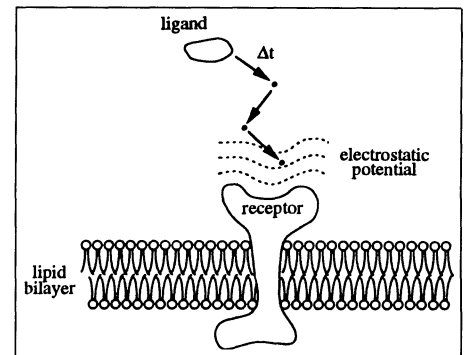
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Quantitative Cell Biology

Receptors. Models for Binding, Trafficking, and Signaling. DOUGLAS A. LAUFFENBURGER and JENNIFER J. LINDERMAN. Oxford University Press, New York, 1993. x, 365 pp., illus. \$69.95 or £50.

Curare, used for centuries by the Indians of the Amazon basin as an arrow poison, was brought to England by Sir Walter Raleigh in the 16th century. Claude Bernard began a systematic investigation of its action in 1850. But it was J. N. Langley, examining the antagonistic effect of curare on nicotine stimulation of skeletal muscle nearly a century ago, who concluded: "Since neither curare nor nicotine, even in large doses, prevents direct stimulation of muscle from causing contraction, it is obvious that the muscle substance which combines with nicotine or curare is not identical with the substance which contracts. It is convenient to have a term for the specially excitable constituent, and I have called it the receptive substance. It receives the stimulus, and by transmitting it, causes contraction" (*Proc. R. Soc. London Ser. B* 78, 170 [1906]). These two principles—the recognition capacity for specific ligands and the subsequent ability of the ligand–receptor complex to initiate a biological response—form the basis of our current understanding of receptor biology. In fact, the role of ligand–receptor interactions in fundamental cellular functions is one of the central themes in biology today, from bacterial chemotaxis to the mechanisms of the new anti-thrombotic agents.

The development of theoretical models of ligand–receptor interactions and their mathematical basis was initiated by A. J. Clark in 1926. Few of the basic principles have changed, but over time increased understanding has added complexity. Fortunately for those working in this area, Lauffenburger and Linderman's *Receptors: Models for Binding, Trafficking, and Signaling* draws on mathematical and cellular bioengineering concepts to lay a detailed foundation in three of the major concep-



"Brownian dynamics calculations for the movement of a ligand. The position of the ligand after a time step of Δt is determined by its previous position, the influence of deterministic electrostatic forces, and the random thermal displacement." [From *Receptors*]

tual areas of receptor biology: (i) cell-surface receptor–ligand binding fundamentals, (ii) receptor–ligand trafficking, and (iii) signal transduction. The extraordinary rapidity of the pace of research in all three areas, but especially signal transduction, necessarily has restricted the contents of the book to specific examples. The authors have chosen wisely. In a section on receptor–ligand trafficking they thoroughly dissect the intracellular itinerary of the epidermal growth factor receptor. The emphasis is on mathematical modeling and the theoretical and practical evaluation of biological data. For those who are not mathematically fluent, the models may be overly detailed. Yet the biological overviews provide an adequate context for them. Surprisingly, neurobiologically important ligands and receptors, such as the excitotoxic agents—which are currently generating tremendous excitement in the field of receptor biology—are not mentioned in the book. Despite this omission, given the molecular manipulations now possible for ligands, receptors, and their associated constituents, the conceptual framework in quantitative cellular biology provided here is a welcome one.

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Books Received

Ancient American Inscriptions. Plow Marks or History? William R. McGlone *et al.* Early Sites Research Society, Sutton, MA, 1993. xvi, 415 pp., illus. Paper, \$19.95.

Ancient DNA. Recovery and Analysis of Genetic Material from Paleontological, Archaeological, Museum, Medical, and Forensic Specimens. Bernd Herrmann and Suzanne Hummel, Eds. Springer-Verlag, New York, 1993. xii, 263 pp., illus. \$69.

Ancient Technologies and Archaeological Materials. Sarah U. Wisseman and Wendell S. Williams,