Toward a Unitary Theory of Mind

The Architecture of Cognition. JOHN R. ANDERSON. Harvard University Press, Cambridge, Mass., 1983. xiv, 346 pp., illus. $25. Cognitive Science Series, 5.

Human cognition encompasses a host of complex skills required for such functions as perception, memory, language use, reasoning, problem-solving, and learning. Perhaps mental life has an essential unity despite the diversity of its component functions; however, there are both pragmatic and theoretical reasons to doubt that a unitary cognitive theory will be forthcoming. On the pragmatic side, the methodology of information-processing psychology has promoted the development of detailed models of performance in particular experimental tasks, seldom linked by an overarching theory. On the theoretical side, writers such as Chomsky and Fodor have argued that certain mental skills (most notably, language use) involve highly specialized mechanisms distinct from other aspects of cognition. In this view, the differences among cognitive functions are more fundamental than any similarities, and the quest for a unitary theory is but a futile distraction from deeper analyses of individual skills.

There is really only one satisfactory rebuttal to such skepticism, and that is actually to develop a rigorous general theory of mind. This is the task John Anderson has set for himself. The research program that has resulted is perhaps the most ambitious in cognitive psychology. Its landmarks are three monographs by Anderson: *Human Associative Memory* (1973), coauthored with G. H. Bower; *Language, Memory, and Thought* (1976); and now *The Architecture of Cognition*. By "architecture" Anderson means the basic principles of operation that govern the performance of the human cognitive system. Anderson believes that a common set of principles applies across the entire range of cognitive functions, and that a theory specifying these principles constitutes a unitary theory of mind. This book is his current statement of such a theory.

Anderson's theory is a revision of the ACT system presented in his 1976 book. ACT ("Adaptive Control of Thought") has gone through several reformulations, culminating in the present version, called ACT*, which Anderson claims is essentially its final form. ACT* is a complex synthesis of ideas from artificial intelligence and cognitive psychology. It takes the form of a process model describing the flow of information within the cognitive system, formalized mathematically and instantiated to varying degrees by several computer simulations of particular cognitive tasks. ACT*, like its precursors, assumes a fundamental distinction between declarative knowledge (that is, knowing *that* something is the case) and procedural knowledge (that is, knowing *how* to do something). Declarative knowledge is represented by a network in which nodes represent "cognitive units," whereas procedural knowledge is represented by "production rules"—conditional imperatives of the form, "If a certain condition holds, then perform a certain action." At any time a portion of the network is activated to some degree; active cognitive units are matched against the conditions of rules (their "if" portions); as soon as an adequate match is obtained for some rule, its specified action (the "then" portion) is executed. The activation state of the network is then changed and the processing cycle iterates.

The Architecture of Cognition is in many ways a revision of Anderson's *Language, Memory, and Thought*, and the contribution of the new book must be evaluated in part by comparison with the prior book and theory. At the general level of description presented above, the new theory is virtually identical to its precursor. However, at a more detailed level a number of changes are noteworthy. Activation of cognitive units is now a matter of degree, rather than all-or-none; and asymptotic level of activation, rather than time for activation to spread through the network, is the primary determinant of processing time. The issue of "conflict resolution"—determining which of multiple possible rules should be executed on a given cycle—is now handled solely by the pattern-matching process that compares active nodes in the network to conditions of rules. Several factors, such as level of activation of nodes, the "strength" of rules, and the specificity and completeness of the match, influence the time required for conditions to be satisfied; the first rule to have its condition satisfied is selected for execution. Another theoretical shift, one that is surprising given Anderson's earlier role as a leading proponent of the view that all declarative knowledge is represented in a "propositional" memory code, is his espousal of a "tri-code" theory of representation. Cognitive units can now be propositions, spatial images, or temporal strings. However, since the implementations of ACT* remain entirely propositional, the chapter on knowledge representation makes little contact with the rest of the book.

As in the earlier book on ACT, Anderson uses his theory to explain various memory phenomena observed in the laboratory. However, increased attention is given to problem-solving applications; ACT* is more directly guided by goals than was the earlier theory. In addition, mechanisms for acquiring new rules on the basis of experience are more fully worked out. A major theme of the book is that across many different domains general induction mechanisms can incrementally improve complex rule-governed skills. As in his earlier book, Anderson audaciously applies his inductive principles to the domain for which the strongest claims for domain specificity of learning have been made—the acquisition of syntax. Two new simulations provide evidence that, under certain specified conditions governed by assumptions about the information available to children learning language, ACT*'s induction mechanisms can acquire rules sufficient to generate sentences with rudimentary syntax. Anderson also bolsters his case for the generality of inductive mechanisms by pointing out parallels between syntactic transformations and transformations of plans for generating problem solutions.

Anderson's earlier theoretical statements have elicited a wide range of reactions among cognitive psychologists. Few have failed to be impressed by the formal sophistication of his theoretical work or the sheer breadth of his aspirations. Some who have offered empirical evidence apparently contradicting his theory have been frustrated in their attempts to hit a moving target, since Anderson has readily revised his theory in the light of new findings. Partly as a result, some have worried that ACT is less a predictive theory than a very general framework that imposes few detailed constraints on the nature of the cognitive system. And the most skeptical critics have claimed that the search for a general theory of cognition is simply a wasteful misdirection of energy.

The Architecture of Cognition is likely to provoke a similar mix of reactions. I would say, however, that, despite its complexity and flexibility, ACT* is a more clearly specified theory than its precursors. It has evolved to the stage at which evasion of disconfirming evidence may not be an easy option. Furthermore, Anderson's stress on generality is something the field clearly needs. Perhaps it is premature or even impossible to develop a general theory of cognition, but we will never know unless someone is willing to give it a serious try. And in proposing specific mechanisms of inductive learning Anderson focuses attention on a topic now widely recognized as critical to gaining understanding of human intelligence.

Those familiar with Anderson's earlier monographs will find that, although his latest is not an easy book, it is clearly written and more concise than its predecessors. It deserves the attention of researchers in cognitive science.

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Microbial Habitats

Microbes in Their Natural Environments. Papers from a symposium, Conventry, England, April 1983. J. H. SLATER, R. WHITTENBURY, and J. W. T. WIMPENNY, Eds. Published for the Society for General Microbiology by Cambridge University Press, New York, 1983. x, 498 pp., illus. $67.50. Symposia of the Society for General Microbiology, 34.

This collection of 12 papers is the proceedings of the 34th symposium of the Society for General Microbiology. According to the editors, the book was intended to bring together a group of manuscripts that discuss "the reality of microbial life" in natural ecosystems. What constitutes ecological reality for the editors is unclear, but their actual goal appears to have been to assemble a group of papers on modern approaches to microbial ecology that emphasize mixtures of laboratory and field experimentation. Such approaches presumably are more likely to yield information that is relevant to natural ecological processes than are approaches that emphasize only field or only laboratory work. The editors have generally succeeded in assembling such a group of papers.

For example, the book contains an excellent paper by David C. White concerning methods for the analysis of microbial activities and biomass in situ. Topics examined include community composition status and the difficulty of applying analytical methods in situ without the introduction of artifacts. This paper should be required reading for all those who study microbes in situ.

Other particularly informative papers include one by Richard G. Burns and one by Darryl C. Reanney, Peter C. Gowland, and J. Howard Slater. The paper by Burns discusses enzyme-substrate interactions in soil, particularly interactions involving polysaccharases and proteinases. It is among the best reviews of this topic available. The paper by Reanney *et al.* presents a lucid discussion of genetic interactions among natural microbial populations. It contains valuable information regarding transfer mechanisms and how these may or may not function in natural ecosystems.

An interesting paper by J. Greg Zeikus discusses metabolic communication between biodegradative populations in nature. The paper contains 39 citations of Zeikus's work and is mostly a review of work performed in his laboratory during the past ten years. The review ranges over a variety of topics, concentrating on anaerobic degradation of biological polymers and methanogenesis in lake sediments. Discussions of mixed-population anaerobic food chains are interesting and useful updates of this very lively subject. One weakness in the paper is its oversimplification of what happens to the plant polymer lignin in anaerobic environments. The statement that "lignin and related high molecular weight aromatic polymers . . . are not significantly decomposed in anaerobic environments" is far from proven. It may turn out to be correct; however, one set of experiments from one environment (Lake Mendota sediments) is not a sufficient basis for such a sweeping generalization.

The quality of other papers in the book is variable but generally high. Topics discussed include spatially heterogeneous laboratory models and microcosms (Wimpenny, Lovitt, and Coombs), the relevance of pure culture studies to natural ecosystems (Tempest, Neijssel, and Zevenboom), mechanisms of microbial energy transduction and solute transport (Konings and Veldkamp), microbial adaptations toward survival in hostile environments (Dow, Whittenbury, and Carr), bacterial motility and taxes (Rowbury, Armitage, and King), microbes and their interactions with surfaces (Wardell, Brown, and Flannigan), the carbon cycle in aquatic ecosystems (Ormerod), and the challenges provided by nature to microbial survival in natural environments (Stewart).

This book should be useful for specialists in microbial ecology, particularly those of us who teach the subject to university students. It is a recommended acquisition for the libraries of most universities. The book provides a nice summary of some of the successes in this field.

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Plant Structures

Xylem Structure and the Ascent of Sap. MARTIN H. ZIMMERMANN. Springer-Verlag, New York, 1983. x, 143 pp., illus. $19.50. Springer Series in Wood Science.

The comparative morphology of wood provides us with a well-documented and dramatic evolutionary series. The invasion and occupation of land by higher plants were closely linked to the evolution of both a support and a water transport system, namely the xylem. Thus the vast majority of the land plants are aptly classified as the Tracheophyta. The cell walls of the xylem contain cellulose for strength, hemicellulose as a matrix, and lignin for rigidity. These cell wall constituents were fabricated into tube-like cells, that is, the tracheids. Support is provided by a tough, rigid wall of helically wound microfibrils of cellulose embedded in a matrix of hemicellulose and encrusted with lignin. For transport the tracheid is programmed to eliminate its cytoplasm at functional maturity, leaving a hollow center (lumen) to serve as a water conduit. Cell-to-cell transport is facilitated by interconnecting holes termed bordered pits. The borders and membranes of these pits are constructed in such a way that structural weakness due to the pitting is minimized. Tracheids in coniferous plants have perforated membranes that have thickened disks in the center that can fold over and seal off the pits under certain conditions.

As Martin Zimmermann points out in this excellent monograph, the tracheid was so successful that few improvements were made for 300 million years. With the advent of the angiosperms a xylem appeared that had fiber tracheids for support (primarily) and vessels for transport. Each fusiform initial of the cambium produces a vessel element, and these vessel elements align themselves vertically, eliminate their protoplasts and end walls (at least partially), and form hollow vessels that in ring-porous