Book Reviews

A Theory of the Mind

Intelligence. Its Organization and Development. MICHAEL CUNNINGHAM. Academic Press, New York, 1972. x, 174 pp., illus. $8.95.

This book describes a general theory of cognitive development, one that attempts to unite the theories of Piaget with a Hebbian (and hence potentially computer-simulation) approach. While the book achieves this aim only discursively—no running program yet exists—it does seem to me to fill in a good bit of the gap between these two approaches. In fact, if certain ambiguities in Cunningham's theory can be resolved, I think it may lead to a major new paradigm for the study of intelligent behavior. Such a paradigm would overcome important problems that seem to be holding back computer simulation now.

Cunningham begins by setting up a formalism, consisting of 18 explicit specifications. These define the nature, operation, and progressive development of a set of cognitive "elements" and links connecting these elements. At an initial state, birth, there would be some elements that represent input sensors, some that represent output effectors, and certain built-in links connecting sensor elements to effector elements. Activation of sensor elements by stimuli (or by internal needs) would pass across the built-in links to produce innate reflexes. During operation, however, the system continually grows both new elements ("memory elements") and new links among these, and thus eventually develops a large network that passes activation around within itself as well as from sensory and to effector elements. Two critical questions for such a system are when and how activation is to move across links to other elements, and when and how new elements are to be added to the system. Cunningham's specifications solve the first question by stating that at any one moment only a certain number of elements are able to transmit activation ("reverberate"), these always being those with the highest current levels of activation. This avoids the need to posit thresholds within the network itself. The number of elements that can reverberate at a particular moment (the mechanism's "attention span") is not a constant, but rather is continually being adjusted. Any increase in this attention span allows more elements to transmit information, and hence broadens the organism's sensitivity. Cunningham's specifications cause such an increase to occur when the organism encounters stimuli for which it has no ready response (novel stimuli), and a decrease to occur when it encounters stimuli that evoke particularly intense responses (fearful stimuli, for example). Thus an increase of attention span constitutes a generalized "orienting response," and a decrease is a generalized "defense response." Both these responses also involve counterbalancing changes in the intensity of the organism's neural output; in an orienting response this intensity lowers, so that the organism's increased sensitivity is accompanied by lessened motor activity (or, in some cases, lessened control over motor activity). Since Cunningham's rule for adding new elements depends on elements' reverberating (being in attention span), learning varies with orienting versus defense responses. This establishes an "equilibration" of assimilation and accommodation like that which Piaget describes, and in general allows Cunningham to offer explanations of a great many learning phenomena.

Cunningham's major effort, in fact, is devoted to just such explanations, to indicating how a mechanism or organism governed by his specifications would grow new elements so as to become capable of more and more intelligent behavior. Therefore, although this demonstration is basically only a verbal one, it is hinged to the workings of a small set of rules; his arguments are therefore relatively precise and, to me at least, generally credible. This credibility, I hasten to add, is not to be obtained without a good deal of work on the part of the reader and, at some points, a rather high tolerance for hand-waving past incompletely worked out details. However, for the reader willing to provide both work and tolerance, the book offers what seems to me an impressive demonstration indeed. In particular, it traces how successive additions to a mechanism's growing network of elements could cause its behavior to pass naturally through the successive stages of Piaget's sensory-motor period. Less specifically, but still very interestingly, Cunningham goes on to indicate how a number of kinds of conceptualization and language behavior also eventually develop, based on the same but further-developed memory, operating under the same original specifications. Along the way he shows how a great number of standard psychological notions would be interpreted within such a mechanism—often in a fresh and suggestive way. For instance, his treatment of short-term memory is not as a basic component of the model, but rather as a cycling of activation within substructures of memory elements that become richly and circularly interlinked. Thus short-term memory is a capability the network would develop separately for particular subject matters, as its experience with them accumulated.

Perhaps the most obvious weakness in Cunningham's specifications is their lack of any basic rule or rules which would allow his mechanism to collapse a whole bundle of interconnected elements into a single representative element for purposes of attention span and learning. Even though Cunningham realizes at one point that he is "skipping over this," he later often seems to forget he has done so. Thus in describing well-learned schemata he is led to say:

> Creation of new elements also depends on how strongly interlinked each system [of interlinked elements] is; if a system is so well interfacilitated that it can fill attention span with its elements and only its elements, then no learning will take place. . . . But, if elements from other systems that are not already linked to the reverberating system can [start to reverberate], then there is a possibility that new coordinations may be formed. *As the maximum attention span increases with maturity, systems that once filled the attention span will no longer do so, and new elements will be added.* Thus, learning will tend to keep a well used system at a certain level of complexity and self-sustaining interconnection. A gradually

maturing attention span sets this certain level of complexity and thereby sets a limit on learning. [Pp. 111–12. Emphasis mine.]

This seems to me all wrong. Surely more thorough learning of a skill itself frees more of one's ability to notice and to learn other things; when we first ride a bicycle, or ski, it takes all of our attention; our later ability to do it with less demand on our attention is surely not to be explained solely in terms of a general maturation of attention span. The problem here is that Cunningham is taking his own specifications too seriously, ignoring their lack of any provision to treat bundles of elements as a single element. He himself in fact continually finds it essential, in order to talk about his model's operation, to allow the notion of a memory element to refer to things at very different levels, from something like a single neuron's firing clear up to a whole complicated concept or skill. It seems to me that this is correct, but that it is essential to give the mechanism itself this same kind of ability. If it had this, he would not find himself obliged to keep relying on a general maturation in the size of attention span to explain people's increasing ability to learn about and attend to one thing as they do another.

However, despite problems of this kind, Cunningham has succeeded better than I thought anyone could succeed just yet in stating a set of rules capable of developing a structure which in turn seems basically capable of producing a really human-like range of intelligent behavior. Herein lies the first reason I suspect his book may well point to a major new paradigm for cognitive theorists: it would move computer-simulation efforts up a level of abstraction. Although attempts at building computer programs to simulate cognitive behaviors have taught us a great deal, these efforts, after first illustrating a few exciting concepts, then seem always to disappear in a morass of details. The exploration of general laws —science—loses out to a peculiar sort of programming pedantry; each project turns into a tour de force in the management of detailed instructions. I suspect this is inevitable as long as researchers attempt directly to program machines *to perform* cognitive tasks, rather than *to learn to perform* them. The only way for a simulation project to remain an exploration of general principles, then, is for its members themselves to program only learning systems, leaving all performance capabilities but the simplest reflexes to be developed by the learning systems. Earlier efforts to program general learning systems, such as the EPAM programs, simply did not develop structures of sufficient flexibility to produce capabilities across an interesting range of cognitive performance. Cunningham's looks to me as though it may, given sufficient tinkering.

There is a second focus of present computer-simulation efforts which Cunningham's work would change. This is the tendency among computer simulators to let the sequentiality that is natural to a computer lead them to view cognition as also guided by essentially sequential processes, and thus to tacitly assume that cognitive processing is the running of programmed sequences of actions—routines that have been previously designed to attain goals or solve problems in the way of goal attainment. This view is likely to seem natural to philosophers who are used to treating distinctions such as objective-relativistic as strict dichotomies (see for example Shapere's attack on Kuhn's "paradigm concept" in *Science* **172**, 706 [1971]), and to others who are accustomed to thinking of thought or natural language as some sort of symbolic logic. Whereas most computer simulation has adopted this kind of view, Cunningham's theory (and the brief proposal for a simulation of it that he gives) would lead to simulations that treat behavioral and cognitive acts as emerging from a "richly parallel" process, a sort of seething, or "pandemonium," to use Selfridge's term, that goes on more or less continually in a very complex memory. To anyone who thinks that human thought is better characterized by something like Molly Bloom's soliloquy than by, say, a proof in symbolic logic, this will seem a turn in the right direction.

In summary, I think Cunningham's book is of major significance, even though I must also add that I think it pushes discursive treatment of his theory about as far as it is fruitful to go. If he or anyone else really wants to discover the potentials and flaws of this conception, the way to proceed now is to start trying to make it run as a program.

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Use of Diffraction Patterns

Optical Transforms. H. Lipson. Academic Press, New York, 1972. xii, 436 pp., illus. $22.50.

This book combines two areas that are not usually considered together, yet have basic similarities. One is the study of crystals, organic molecules, polymers, and other such structures by means of the diffraction patterns they produce. The other is holography and the processing of information by means of coherent optical systems. In each case, the formation of diffraction patterns is of essential importance. Since the two areas are widely separated in practice, there is a question of whether any single individual could have written a book such as this. In fact, this book has about a dozen authors, each of whom has contributed a chapter or two.

The greater part of the book deals with the first area, the use of diffraction patterns to unravel the structure of molecules and crystals. The various authors treat related topics, one choosing organic molecules, another polymers, another crystals, and yet another the basic theory of Fourier synthesis. The similarity of the topics and the diversity of authorship result in some overlap of material, but this effect seems to be minimal and is not undesirable, since the viewpoints and tutorial approaches are different.

The diffraction patterns may be formed by illumination of the materials with x-rays or with electrons. Simulation studies are made by examining the diffraction patterns formed from specially prepared masks illuminated with coherent light. Inferences drawn from these various patterns or from their comparison, along with computer analyses and much ingenuity, lead to determination of the molecular or crystal structure. The procedure, described by the various authors in different ways for various classes of objects, appears to be difficult, laborious, and quite challenging.

The text is supplemented by hundreds of pictures of diffraction patterns, which considerably assist the reader in his comprehension of the material.

The other basic area is treated in the two chapters on holography and optical processing. Each is capably written and gives a proper account of its subject, both from the historical viewpoint and in terms of current activities. Optical processing, in the sense in which the term is used here, is con-