Human and Artificial Intelligence: Bridging the Gap

Gary L. Drescher
Made-Up Minds: A Constructivist Approach to Artificial Intelligence
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Review by
Valerie J. Shute

Gary L. Drescher is a scientist with Thinking Machines Corporation. ■ *Valerie J. Shute, research psychologist at Armstrong Laboratory, Human Resources Directorate (Brooks Air Force Base, Texas), is recipient of the Air Force Laboratory "Star Team Award" for excellence in Basic Research–Learning Abilities Measurement Program. Shute is coauthor, with R. Glaser, of the chapter "An Intelligent Tutoring System for Exploring Principles of Economics" in R. E. Snow and D. Wiley (Eds.)* Improving Inquiry in Social Science: A Volume in Honor of Lee J. Cronbach; *author of the chapter "A Comparison of Learning Environments: All That Glitters . . ." in the forthcoming S. P. Lajoie and S. J. Derry (Eds.)* Computers as Cognitive Tools; *and coeditor, with J. W. Regian, of* Cognitive Approaches to Automated Instruction.

In this book, Drescher details the inception, development, and preliminary results of his computer program "who" learns. The two stated goals of this research include understanding the human mind as well as designing an artificial mind. Often, when artificial intelligence (AI) and psychology are forced to unite in a major research project like this, one dominates whereas the other is subservient. However, to his credit, Drescher has given each of these disciplines approximately equal weight and significance in the liaison, making this project much more than simply another AI program or another model of learning. So the book has a little something for everyone: a nice overview of Piagetian development, a good summary of the system's architecture (neural and computer implementation), details of the system's learning from an actual run, and a comparison to other AI learning programs.

The principle agent in Drescher's program is the *schema mechanism*, "a general learning and concept-building mechanism intended to reproduce aspects of Piagetian cognitive development during infancy" (Preface). The intriguing part of the program, one that sets it apart from many other learning programs, is that it starts out with very few primitives embedded in the system (i.e., minimal a priori knowledge of the world). Thus, this tabula rasa condition is similar to a human neonate in whom learning builds up from scratch, over time. Therein lies the power and beauty of his system. Starting with just a handful of primitive actions, the system learns much like a human infant.

The schema mechanism consists of several important features: the machinery for empirical learning (marginal attribution), abstraction (composite actions), and conceptual invention (synthetic items). These components "explain" Piagetian development as well as provide a basis for assessing the functionality and success of the computer-learning system. Some important questions addressed by the book include, Can this made-up mind actually acquire new knowledge and skills on its own, just what does it learn, when does it learn this, and how does this map onto Piaget's developmental stages? The answers to these questions are deeply ensconced within the 213 pages, and the extraction is not trivial.

Because of the way this particular book is written (i.e., the density of text and the presumption of familiarity with AI techniques and conventions), this is not a book for laypeople (or lazy people). Books of this genre are, too often, more technical and less readable; however, they need not be so difficult to read. For example, *Mind Bugs* (VanLehn, 1990) was, like Drescher's book, similarly based on the author's dissertation at the Massachusetts Institute of Technology and involved the marriage of AI and psychology. However, it is quite readable. VanLehn succeeded in part by including numerous examples that made the book meaningful and fun. Moreover, his text was clean and simple. The current book by Drescher could definitely have benefitted from more examples in the text to illustrate different ideas, techniques, and findings. Also, the writing style could have been simplified. For instance, when discussing how the program deals with redundant attribution, Drescher writes that

> the embellishment of deferring to a more specific applicable schema ensures that as some (conjuncts of) disjuncts of a disjunctive condition are identified, it becomes easier to detect the relevance of (conjuncts of) other disjuncts—the other disjuncts need only compete against the "background" probability of the schema's success due to yet-unidentified conditions. (p. 76)

This sentence is typical of many of the sentences contained in this book, making it difficult to distill the often very good ideas embedded within. I found myself having to reread many parts of the book just to figure out what he was trying to impart; I struggled not to lose sight of the forest for all the trees. Even straightforward notions like "schemas auxiliary data" require lots of work on the reader's part:

> A schema's correlation is the ratio of the probability with which a transition to the schema's result state obtains when the schema is activated to the frequency with which that transition obtains when the schema is applicable, but not activated (here again, a tabulation of actual frequency serves as a presumptive probability). (p. 55)

Finally, many of the important notations and conventions used to illustrate the program's learning and environment have to be induced by the reader. For instance, the notation for the grid framework underlying the microworld was used from the beginning of the book, yet the (somewhat unconventional) x- and y-axis numbering scheme was not introduced until page 117. Even then, one has to induce the numbering scheme from the individual primitive items table. For hand-position items, numbering starts in the lower left corner at (1,1). However, visual-field items apparently start at (0,0). Also the reader has to induce that glancing at an object results in the object's movement in the opposite direction (technically correct, but sure confusing). Then there are the five foveal regions that reside within the visual field and have a different numbering scheme altogether.

However, if considerable effort is made, fascinating kernels can be found within. Although Drescher is careful to assert that the current implementation represents a preliminary step toward the goal of representing constructivist learning, these baby steps are really quite im-

pressive. He succeeds in recapitulating some early landmarks of Piagetian development, including "the anticipation of visual effects of hand motions, learning how to bring the hand into view, discovering intermodal coordination (e.g., touching what's seen, and vice versa), conceiving of persistent visible and palpable objects, and discovering their coextension" (p. 209). Although this brings us up to what Piaget classifies as the sixth stage of infant development (or approximately 18 months), as a computer program, this represents a great achievement. For those of us who have watched real infants develop during this time frame, the cognitive gains are enormous.

Briefly, the program learns as follows. A schema consists of a context, an action, and a result. Each one of these can become embellished over time and experience with the surrounding "world" (e.g., extended contexts and composite actions). For each primitive sensorimotor action (e.g., HandBackward) a "bare schema" (consisting of just the action with empty slots for context and result) serves as the basis for the discovery of the effects of its action ("result spinoffs") as well as relevant context conditions ("extended contexts"). This motivated search for results and contexts comprises a system's exploration of the environment. The findings from these explorations are then added to the schema's slots creating progressively more knowledge of the world. Statistics are maintained in the schemata's control structures about the schemata's success and frequency rates (i.e., reliability and correlation indices). Other data, such as duration and cost, are included in the control structure, contributing to the system's decision as to which schemata should be activated and when.

Although much of the book, necessarily, serves to establish the framework of the program, the heart of the book resides in Chapter 6, titled "Synopsis of Schema Mechanism Performance." This section recounts the results from a particular reference run of the program. After about one full day of real time running on the Connection Machine (CM2), over 7,000 schemata (empirical learning), 184 synthetic items (conceptualizations), and 343 composite actions (abstractions) were built. Some kind of categorization of these extraordinary findings would have been very helpful to the reader, especially as they relate to actual schemata developed by infants. However, that was not offered. Instead, 36 loosely connected schemata were depicted representing a variety of events (e.g., foveal glance contexts, positional hand actions, etc.). Of those more than 7,000 newly created schemata, which mapped on to realistic schemata, what novel conceptualizations were created, and so forth? Could the program learn to suck its electronic thumb?

The section in the book outlining future developments (Chapter 7) was almost as compelling as the actual accomplishments summarized in the previous chapter. In particular, the idea of virtual structures and mechanisms was very appealing (albeit, currently not implemented). An example includes "subactivation" whereby the system essentially runs "mental" simulations to expedite learning novel concepts. Excellent intended extensions were rendered. Finally, the book included many tangential but fun observations scattered within. For instance, there were fascinating and informative footnotes distributed throughout the text (e.g., Weizenbaum's description of a program simulating infantile autism that cannot be distinguished from a real autistic patient because it gives no response). Also, the acknowledgments included recognition of such diverse entities as the Connection Machine and the Grateful Dead (what a long, strange trip, indeed). Finally, even the way the book ended was inventive (context = peace sign, action = The End, result = happy face). It was applicable.

In conclusion, I experienced a kind of love–hate relationship with this book. Although I greatly admired the accomplishments and potential of this computer program, the necessary investment of time and energy required to extract meaningful information hampered my enjoyment. The lesson to be learned is that when writing a book, especially such a rich one as *Made-Up Minds*, one should really try to phrase things as clearly as possible. Otherwise, the message gets lost in the medium.

Reference

VanLehn, K. (1990). *Mind bugs: The origins of procedural misconceptions.* Cambridge, MA: MIT Press.

Sampling Instructional Psychology: A Tall Order for a Small Book

Review by
David F. Lohman

Anne McKeough and Judy L. Lupart
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Anne McKeough, associate professor of educational psychology at The University of Calgary (Alberta, Canada), is author of the chapters "A Neo-Structural Analysis of Children's Narrative, and Its Development" and "Testing for the Presence of a Central Social Structure: Use of the Transfer Paradigm" in R. Case (Ed.) The Mind's Staircase: Exploring the Conceptual Underpinnings of Children's Thought and Knowledge *and coeditor, with J. L. Lupart, of the forthcoming* Teaching for Transfer. ■ *Judy L. Lupart, associate professor of educational psychology and director of the Centre for Gifted Education at The University of Calgary, is coauthor, with P. Fry, of* Cognitive Processes in Children's Learning: Practical Applications in Educational Practice and Classroom Management *and founder and editor of* Exceptionality Education Canada. ■ *David F. Lohman, associate professor of educational psychology at the University of Iowa (Iowa City), is coauthor, with R. E. Snow, of the chapter "Implications of Cognitive Psychology for Educational Measurement" in R. Linn (Ed.)* Educational Measurement (3rd ed.) *and author of the chapter "Intelligence, Learning, and Instruction" in T. Husen and T. M. Postlethwaite (Eds.)* International Encyclopedia of Education (2nd ed.)