BOOKS: COGNITIVE SCIENCE

If You Build It, Will It Know?

Arthur B. Markman

Embodied cognitive science is a growing area of research that attempts to understand intelligence by constructing actual or simulated agents. This work takes as a core assumption that a true understanding of the processes of intelligence requires actually building agents that are capable of surviving autonomously in the real world. The approach is a reaction to the last 50 years of developments in the cognitive sciences (an amalgam of psychology, artificial intelligence, linguistics, philosophy, and related disciplines). Like many other proponents of behavior-based artificial intelligence, Rolf Pfeifer and Christian Scheier argue in *Understanding Intelligence* that the traditional methods for studying intelligence have failed to provide sufficient insight into what intelligence is and how it works. The root of this failure, they contend, is that cognitive science has focused on complex internal mental processes to the exclusion of the factors that permit intelligent agents to interact with their environment.

Understanding Intelligence
by Rolf Pfeifer and Christian Scheier
MIT Press, Cambridge, MA, 1999. 717 pp. $60. ISBN 0-262-16181-8.

Understanding Intelligence is a comprehensive and highly readable introduction to embodied cognitive science. It will be particularly helpful for people interested in getting involved in the construction of intelligent agents. Sections of the book describe general design philosophies for intelligent agents and methods for evaluating them. These include several case studies; other sections discuss numerous examples of robots and simulations. Each chapter concludes by raising two issues that lead the reader beyond the information given within it. Each also offers a series of bulleted summary points and suggested further readings that students will find useful. In addition, the authors have developed a website that contains computer programs (with code) for developing simulations of intelligent agents and provides many suggestions for those who want to build their own robots as research tools.

Over the past 20 years, a number of robots and simulated agents have been developed that can carry out simple behaviors in real time. They avoid obstacles, move autonomously, go to power sources when their batteries start to drain, and even perform menial tasks such as collecting objects. Some of these agents, like those developed by Rodney Brooks, are small wheeled creatures that zip around an environment. Others, like the artificial insects created by Randall Beer, simulate walking on legs designed along the lines of those possessed by real organisms.

A central tenet of this work is that building real robots can lead to the recognition of ways that agents can exploit the structure of the world to behave intelligently. For example, one simple set of robots described in the book learns to classify large and small cylinders by circling around them. The circling behavior can be implemented by giving the robot a few simple motor routines. Because the relative speed of the two wheels of the robot are more similar when circling a large cylinder than when circling a small one, the robot is able to correctly classify these objects without needing an elaborate vision system. This information is only available because the robot actually exists in the world and needs a system for locomotion.

A second major theme of this work is that the only way we will ever understand intelligence is to build autonomous agents. This claim stands in contrast to approaches, common in cognitive science, that focus on solving well-specified problems without concern for autonomy. For example, the authors offer Deep Blue—the computer program that beat world chess champion Garry Kasparov a few years ago—as a prototypical case of artificial intelligence methodology. As they point out, this program was successful because it exploited the fact that chess is a game with specific rules that allow the set of possible moves to be enumerated. Thus, Deep Blue was a technological marvel (it was able to search through a large space of possible moves quickly) but not a generally intelligent one.

The embodied cognitive science approach has provided genuine insights into behaviors of real animals. Robots and simulated agents have been developed that suggest, for example, explanations for the way some desert ants use polarization patterns of sunlight to navigate and how birds can fly in flocks by following a few simple (and implicit) rules. Still, these behaviors seem a long way from what most people think of as intelligence.

Consider the complexity of categorization. People are able to classify objects in the world, just as the robot previously described was able to classify cylinders on the basis of simple perceptual properties. Human abilities to classify, however, go beyond exploiting simple perceptual and motor regularities in the environment. We classify on the basis of verbal descriptions (such as deciding someone is a Democrat because of their attitudes toward social issues) and on the basis of theories about the way the world works (classifying a person as drunk after they dive into a pool with their clothes on at a party, for example). Further, we use our categories to make predictions (suggesting someone's voting habits after finding out they are a Democrat) and to generate explanations (using beliefs about drunkenness to understand someone's lack of self-control). Humans are also able to use categories to communicate with others about categories—as I am right now with this review.

High-tech tea ceremony. This Japanese tea-serving robot must recognize and manipulate tea, teacups, and saucers.

CREDIT: GEORG FISCHER/FROM R. KURZWEIL, *THE AGE OF INTELLIGENT MACHINES* (MIT PRESS, CAMBRIDGE, MA, 1990)

If no traditional cognitive scientists had attempted to study such problems or if no progress had been made in understanding these abilities, then it might make sense to advocate that embodied cognitive science should become the new dominant paradigm. But many of the examples from the previous paragraph have already been studied, and strides are being made to understand these issues. Furthermore, although the perceptual and motor abilities of the new generation of robots are impressive, it has not been shown that this kind of sensorimotor coordination will provide a better framework for understanding high-level intelligence than the techniques currently being pursued in cognitive science. It seems unlikely, for example, that communicating about categories will involve simple extensions of the processes employed by the cylinder-classifying robot. Pfeifer and Scheier assume that the work done so far will lead naturally to explanations of more complex behaviors, but they do not provide evidence for this assertion.

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It is unfortunate that advocates of new and interesting research methods like embodied cognitive science feel compelled to support their own research program by, in part, denigrating approaches already in use. We should not abandon the other methods of modern cognitive science simply because the use of autonomous agents has shown early success in accounting for sensorimotor behavior. This is not the first time that a rebellious group that met with some initial success in understanding cognition attempted to expand the reach of their methodology to all of cognitive science. The dawn of the cognitive revolution in the 1950s witnessed the development of powerful computer programs like the General Problem Solver (whose architecture is similar in spirit to that of Deep Blue). This work led to predictions that artificially intelligent systems based on these methods would soon outstrip human intelligence. The failure of these overly optimistic prognostications should remind us that no single method is going to solve all of the remaining mysteries of cognitive science. Let us hope that it does not take another five decades to understand this lesson about intelligence.

BOOKS: ASTROBIOLOGY

All Alone After All?

Christopher P. McKay

Are we alone? This question guides the fundamental quest of astrobiology. Certainly interest in the field has surged in recent years, and there is an eager expectation in both the scientific community and the public that somehow we will soon obtain an answer. Lacking data, we guess at where to look and what we might find. But, as geologist Peter Ward and astronomer Donald Brownlee point out, it's important to clarify the "we" in the target of our search. "We" could refer to any life, to animal life, or to intelligent communicative beings. For each target, our search strategy and the expected results might be very different. The rare Earth hypothesis put forward in *Rare Earth* posits that microbial life is common but complex (animal) life is rare. The authors comb through all the aspects of what makes Earth a home for complex life: from deep within its interior, to the solar system, and beyond to the galaxy itself. For each factor they make the case (if not always convincingly) that the situation of our Earth is optimal for the development of complex life. It seems we do live in the best of all possible worlds after all.

For the first three billion years of Earth's history, our planet was populated only by simple microbial life. This pattern, we all agree, is the one most likely to be repeated on other planets. Maybe a shortened version of it even occurred next door, during Mars' early history. Why are we so confident that microbial life is widespread? The arguments in *Rare Earth* are the standard ones: Organic matter is common in the universe. The formation of many biologically important molecules is easily achieved in chemical reactions. The catalytic RNA molecule appears to be a suitable halfway point between proteins and DNA. And, most importantly, it all happened so quickly here on Earth, why not elsewhere as well.

Rare Earth
Why Complex Life Is Uncommon in the Universe
by Peter D. Ward and Donald Brownlee
Copernicus (Springer-Verlag), New York, 2000. 361 pp. ISBN 0-387-98701-0.

Much has been made recently about microbial life in extreme environments, and *Rare Earth* follows suit. But that emphasis is mistaken. Life on Earth is not very tough at all. No life form has yet been found that can grow or reproduce without liquid water. This restricts life to a fairly narrow range of temperatures, –20° to 120°C. By cosmic standards, that's a narrow habitable zone. Despite the rhetoric, recent work in extremophiles has not changed our understanding of the limits to life. The list of life's boundaries from 20 years ago is identical to the current one except that the upper temperature limit has moved from 100° to 113°C. What has expanded is our understanding of the ecology of life in environments difficult for humans to access. Accompanying this has been an increased comprehension of possible liquid water environments on early Mars, subsurface Mars, and Europa.

Nevertheless, I too believe microbial life is widespread. But in the back of my mind there are two uncomfortable facts. The first is that we have only one example of life, evolution, and intelligence. From this we can conclude that such events are not impossible, but any assessment of their probability is uncertain at best. The second is that we currently have no good evidence of any life beyond Earth. The infamous martian meteorite has whetted our appetite for evidence of life but not satisfied it.

The transition from microbial life to complex life (animals) is the key step. Factors that could influence this include a long-lived stable star, a Jupiter to scatter planetesimals throughout the solar system in just the right way, a Mars to perhaps provide the initial seed for life, a large Moon to stabilize the climate, just the right amount of water and carbon to provide for a stable biosphere but not overwhelm it, and, most importantly, plate tectonics. Plate tectonics emerges as the hero in the life story of Earth: "It may be that plate tectonics is the central requirement for life on a planet...." Subduction, volcanism, and plate motions recycle the planet both biologically and chemically and control the temperature. (It is sobering to remember that just 40 years ago plate tectonics was an unbelievable hypothesis.) If plate tectonics is the hero in the epic Ward and Brownlee recount, then meteor and comet impacts, which threaten to wipe out complex life at regular intervals, are the villains.

How do we discover how common life is? how common complex life is? how common intelligence is? By searching as widely as we can. Searching the skies for signals or artifacts of intelligent beings, searching the nearby planets for evidence of a second genesis of microbial life, and searching the nearby stars for habitable planets. We should let our quest be guided by our theories of life and evolution, but we should try not to be constrained by them—they may be wrong. In this spirit, *Rare Earth* provides a sobering and valuable perspective in just how difficult it might be for complex life and intelligence to arise.

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BROWSINGS

Worlds Without End. The Historic Search for Extraterrestrial Life. *R. A. S. Hennessey.* Tempus, Charleston, SC, 1999. 160 pp. $29.99, £18.99. ISBN 0-7524-1450-X.

Hennessey chronicles the major developments in pluralist theories, from ancient Greece to modern television. His samples of imaginative illustrations of life elsewhere in the universe include Paul Hardy's 1887 depiction of martian fauna (above).

CREDIT: P. HARDY/FROM L. SZYRMA'S "LETTERS FROM THE PLANETS," *CASSELL'S FAMILY MAGAZINE* (1887)