In recent years Japan has gained impressive market shares in several areas of trade, including steel, consumer electronics, and automobiles. It's about to happen again in the computer industry, say Edward Feigenbaum and Pamela McCorduck in their book, The Fifth Generation: Artificial Intelligence and Japan's Computer Challenge to the World. The authors claim that the latest Japanese challenge to United States supremacy must be met or "we may consign our nation to the role of the first great post-industrial agrarian society."

The Japanese national 10-year plan to take control of the computer industry began rolling in April 1982 with the aim of engineering the fifth computer generation. At issue is a potential revolution embodied in a new generation of computers that will transform the way we work.

The fifth generation already! For those not at all sure what the first four were, here's a rapid review. Digital computers need switches. In "on" position, the switches signify the number 1 or the logical value "true"; in "off" position, they stand for 0 or "false." When artfully arranged and interconnected, the switches make the computer compute. In the beginning vacuum tubes were used as switches. They were large, slow, and energy greedy. Second came the much smaller, faster, and more efficient transistors used as individual switches. In the third stage, hundreds or thousands of transistors—switches—were manufactured together in preplanned configurations as integrated circuits. In the fourth, comparable arrangements became microscopic in very-large-scale integrated circuits (VLSI).

The fifth generation will certainly bring continued shrinkage of switching elements. More important, in the Japanese view, will be the qualitative changes made practical by advances in computer hardware: generation five is to bring us supercomputers that run expert system software. The new systems will be conceptually as well as functionally different from the previous generations of computers. As the authors explain, the fifth generation "signals the shift from mere data processing, which is the way present-day computers function, to an intelligent processing of knowledge." Fifth-generation systems will be expressly designed to run artificially intelligent programs capable of performing tasks at a level comparable with human experts.

In introducing the reader to expert systems, Feigenbaum, a computer science professor at Stanford University, is playing a song he knows well. In 1965 he produced one of the first expert systems with colleagues Joshua Lederberg and Carl Djerassi. Dendral is an expert system programmed to infer molecular structure when given data available to physical chemists. The program now makes the inferences more reliably than the chemists do and indeed more reliably than its designers.

In Feigenbaum's view, the Dendral program marked several significant changes in artificial intelligence research. After Dendral, expert system programs increasingly turned away from the ivory chessboard toward real-world problems. At the same time, consensus grew that for solving real-world problems expert systems
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required more than abstract problem-solving techniques. Large quantities of real-world knowledge were also needed to develop expert systems.

Medically oriented expert systems contain the most prevalent type of real-world knowledge base. Medical diagnostic aids must be able to reason with method and efficiency; if the system doesn’t know which symptoms indicate which diseases, it will reason about nothing, and no amount of cogitation will produce reliable diagnoses. The Internist/Caduceus expert system at the University of Pittsburgh was designed as a diagnostic aid in internal medicine. Its knowledge base covers more than 500 diseases and 3,500 symptoms of disease. To identify the specific illness of a patient, the physician provides the computer with lab test results and patient history, and the program begins to reason about possible diagnoses.

The computer acts as a consultant, asking the physician questions, suggesting tests when crucial information is missing, or explaining its line of reasoning. Diagnoses are accompanied by confidence ratings such as, “There is a 65 percent probability that the patient has bubonic plague,” or explanations such as, “Spots before the eyes, ringing in the ears, and halitosis seen in combination could indicate either Tasmanian flu or bubonic plague; however, fuzzy tongue and itching behind the knees would eliminate Tasmanian flu.”

Super Logicians
If expert systems already existed as far back as 1965, what are Feigenbaum and McCorduck talking about now? What are the Japanese doing that is so new or threatening? The Japanese are aggressively developing supercomputers optimized to run expert systems, and they are planning mass distribution of expert system use. The authors stress that whoever establishes superiority in knowledge technology will control the balance of world power, regulating both the cost and the availability of knowledge.

The fifth-generation computers envisioned by the Japanese will deal in symbols more than numbers, and with logical operations more than arithmetic ones. Appropriately, their logic processors will be the machine language PROLOG, a logic-oriented programming language developed in Europe. But again, these are to be supercomputers; they will be more powerful and much faster than their predecessors.

The speed of fifth-generation computers will be measured in logical operations per second. The Japanese are aiming for between 100 million and 1 billion operations per second (current speeds are measured in millions of arithmetic operations in the same span). However, the real power of these computers will be in their capacity to reason and expand the boundaries of human intelligence.

Expert Systems

Daniel Farber

Although the knowledge processing industry is still in its infancy, the authors of The Fifth Generation point out that expert systems and the knowledge processing technology required to build them had developed a basic framework by the late 1970s (see Figure 1). The main ingredient of an expert system is knowledge—data that has been selected and transformed into the substance of so-called intelligent machines. Feigenbaum and McCorduck explain that two types of knowledge are involved in forming a knowledge base: factual and heuristic.

Factual knowledge includes facts and opinions commonly accepted among experts in a given field such as law, medicine, or geology. Heuristic knowledge, on the other hand, is a more intuitive, trial-and-error type of knowledge that an expert gains through years of experience—knowledge that can’t be garnered from the factual data of a textbook. Both types of knowledge are essential to forming an efficient knowledge base.

An expert system also requires a problem-solving strategy, or inference system designed to comprehend and manipulate the knowledge base and the specific problem data input into the system. An inference system provides a method by which lines of reasoning can be constructed using common, step-by-step logical structures such as syllogisms. Since real-world knowledge involves a great deal of imprecise knowledge, some inference systems have uncertainty factors built into them.

Of central importance in the design of an expert system are the way the knowledge base is represented as data structures in the computer and the

Since vast amounts of knowledge will be on file on the new computers, large memory banks must be available to accommodate it. Ultimately, the system should contain 1000 characters worth of knowledge on each of 100 million things—as much knowledge, by one estimate, as is contained in the Encyclopaedia Britannica. Tens of thousands of logical rules will be needed to sort through all that lore (e.g., if animal X has warm blood, has hair, and bears live young, then animal X is a mammal). Parallel processing will replace the one-step-at-a-time procedures of the standard von Neumann architecture of today’s computers; jobs will be divvied up so that many subjobs can be in the works simultaneously.
way that knowledge base is accessed for problem solving. These tasks are performed by the knowledge engineers and programmers who design the programs that make up an expert system. Knowledge engineers elicit the knowledge from the minds of human experts, shape the knowledge so that programmers can transform it into viable program codes (knowledge bases), and create the inference systems that use a knowledge base to derive specific results.

Feigenbaum and McCorduck relate that acquiring knowledge from human experts poses a major problem in artificial intelligence research. An expert system is only as good as the knowledge represented in the computer. Currently, knowledge engineers must painstakingly extract heuristic knowledge from human experts through a series of interviews. The process of simulating an expert's thought process and erudition is costly and time consuming. Knowledge, like the human mind, is not easily defined; an expert may not be able to articulate clearly or formulate his or her knowledge in a hypothetical situation.

Knowledge engineers usually present a hypothetical problem to an expert as a way of focusing the knowledge acquisition process, but the situation may not bring out all contingencies. Expert systems in operation today are restricted to narrowly defined areas of expertise to maintain a high degree of problem-solving proficiency. Natural language communication between computers and humans must also be improved to allow for more in-depth exchange between programs and users.

Illustration from The Fifth Generation by Edward A. Feigenbaum and Pamela McCorduck reprinted with permission from Addison-Wesley Publishing Co.

Figure 1: Basic structure of an expert system

Teaching computers to learn—to acquire knowledge independently—is another obstacle. Factors in the human thought process such as emotion, will, and the ability to use errors creatively are as yet beyond the capabilities of an expert system. A computer cannot be said to replicate an expert's knowledge exactly until these design problems are solved. Knowledge acquisitions research is exploring these critical issues in the hope of developing more comprehensive, automatic methods of creating expert systems.

Producing knowledge machines that few people can use will not revolutionize the world economy. The Japanese expect that use will be tremendously expanded if people can communicate with the systems in natural languages such as Japanese, English, or Swahili. Accordingly, researchers will put a major research effort into natural language processing.

The subject of natural language processing brings us to the folks at home. You'll be calling on expert systems whenever you need expert advice. According to Feigenbaum, personal computers powerful enough to support today's modest expert systems (about half a megabyte of memory) are already on the market—even without the Japanese. Home-oriented software should follow in 2 or 3 years.

Are your plants unaccountably turning yellow? Have you found that even your broker can't keep up with the latest money market options? Are you afraid of doctors and lawyers or too poor to call them in when you need them? Expert systems will be on call day or night, providing instant, specific solutions to your problems.

The Japanese, of course, have concerns beyond diagnosing plant diseases. Resource-poor, they must continually raise productivity to compete. They see working smart as the key, and expect intelligent computing to affect every area of their economy—and the world's.
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An AI Potpourri

More than a report narrowly focused on Japanese enterprise, The Fifth Generation is a collection of short essays on the international climate in computational research on artificial intelligence in general, and expert systems in particular. No doubt the essay approach facilitated shared authorship, and it provides bite-sized chunks for easy reading. The format, however, allows a good deal of repetition to creep in and gives the feel of a work made up of pieces that still need to be assembled.

Still, many of the pieces are worth the price of admission. I approached The Fifth Generation hoping to find out what Japanese computer technologists are up to. I found out. I got a clear view of the nascent Institute for New Generation Computer Technology (ICOT), its driven director Kazuhiro Fuchi, and the 40 samurai charged with producing a miracle. I learned how the project was organized in the face of Japanese conservatism, how research is being flexibly structured, and how results are to be continually disseminated.

As for expert systems per se, while purposely avoiding details, the book provides a comprehensible introduction to the concepts involved. There is an informative account of the range of expert system applications, such as furnishing drilling advice on remote oil rigs, trouble-shooting the design of integrated-circuit chips, helping to customize computer systems, analyzing DNA sequences, and heading off power-grid blackouts.

The real issue is whether humans can maintain a sense of worth as machines increasingly take over intellectual tasks.

How does the know-how get into the software? The authors describe how knowledge engineer H. Penny Nii elicits knowledge from human experts for incorporation into expert systems. To their credit, Feigenbaum and McCorduck are aware of the human side of this interchange; they describe the excitement and the awe of the expert who sees or her knowledge transmitted piecemeal to a machine. On the other hand, they tell of the pain of the expert who comes to realize that hard won expertise can be reduced to a few hundred rules. "At first he was disbelieving," say the authors. "Then he was depressed. Eventually he departed his field, a chastened and moving figure in his bereavement."

Emotional and philosophical questions are unavoidable in an essentially popular work on "machines who think" (as McCorduck calls them). With some distaste, McCorduck takes on the overworked question of whether machines really can think. The real issue, she feels, is whether humans can maintain a sense of worth as machines increasingly take over intellectual tasks that only humans have done up to now. She quotes Edward Fredkin of MIT on this point: "Humans are okay. I'm glad to be one. I like them in general, but they're only human. It's nothing to complain about. Humans aren't the best ditchdiggers in the world—machines are. There were people whose thing in life was completely physical—John Henry and the steam hammer. Now we're up against the intellectual steam hammer. The intellectual doesn't like the idea of this machine doing it better than he does, but it's no different from the guy who was surpassed physically." McCorduck notes in the conclusion that the arguments adduced these days to prove computers incapable of thought are similar to those brought out a century ago against the intellects of women. Good point.

Whether or not computers can think, McCorduck, a New York-based science writer, apparently can. An engagingly grumpy presence throughout the book, she presents herself as a seasoned cookie who knew artificial intelligence in knee britches. Expressing a personal stake in the Japanese proposal to produce robot geriatric nurses, she made me smile.

Feigenbaum and McCorduck sometimes disagree, most explicitly on the social consequences of increasing the use of expert systems. Both are concerned about the economic and intellectual alienation of the computer illiterate. On balance, however, Feigenbaum expects people to see the way the wind blows and turn computation to their advantage, particularly as costs decrease. McCorduck is skeptical. The importance of print literacy has been recognized for centuries, she observes, and free books abound in public libraries—but illiteracy persists.

Misgivings

During a recent discussion with Feigenbaum, I asked him whether he anticipated legal problems when computers begin giving advice in earnest. "No," he said, there will always be "a human in the loop" taking full responsibility. Expert systems are designed to aid decision makers, not replace them, he insisted. But aren't expert systems sometimes intended to stand in for absent experts, reason more quickly than humans in the face of impending blackouts and meltdowns, or gather together expertise that no one person commands? We'll see.
Is the book’s Paul Revere tone justified? Can the Japanese really turn the trick of producing a breakthrough? Feigenbaum and McCorduck examine the criticisms leveled at the fifth-generation project by the American artificial intelligence community—overemphasis on logic at the expense of alternative processing methods, and overemphasis on speed and memory capacity at the expense of software in general. Feigenbaum adds his own observation that where expert systems are concerned the Japanese are still wet behind the ears.

The conclusion, however, is that the fifth-generation project will have dramatic results even if the goals are only partly achieved. The Japanese have the equivalent of a well-supported and beautifully organized space pro-

The real power of these computers will be in their capacity to reason.

gram; they may not reach the moon in years, but in trying they stand to learn enough to undercut us in the knowledge processing industry, as they already have in other markets.

Feigenbaum emphasizes that his concern is not xenophobic but economic. (As a scientist, he says he could take a purely internationalist viewpoint.) In my view, his economic concerns are justified but may not go far enough. Even if we keep our share of high-tech markets, there’s ample reason to fear that as automation gallops ahead (spurred on even faster by developments in artificial intelligence and robotics) unemployment will remain a serious problem. It will be small comfort to the American unemployed if the elite who do have jobs are American as well as Japanese. The problem isn’t simply the international distribution of jobs—it’s the distribution of jobs, period. Feigenbaum and McCorduck hope that knowledge-related employment will take up the slack left by the automation of manufacturing and paper shuffling. I hope so too.

A Call to Arms
What’s going on outside Japan? The Fifth Generation devotes considerable space to the infighting and stodginess that robbed England of an early lead in the field of artificial intelligence. Research carried out by other Europeans is treated rather sketchily, and the Soviet Union is fairly written off as hogtied by ideology.

Is the United States responding effectively to the Japanese challenge? No, say the authors. The Microelectronics and Computer Technology Corporation (MCC), a research consortium with participation by such firms as DEC, Control Data, and Honeywell, is probing the issues, but antitrust laws limit the extent of the cooperative research allowed and effectively prohibit the participation of giants like IBM, Hewlett-Packard, and Texas Instruments.

Now under consideration in Congress are research proposals from the Department of Defense and the Senate Committee on Labor and Resources (the latter initiated by Edward Kennedy), but these proposals are many votes away from passage. In the past we’ve seen the GI Bill, The National Defense Student Loan program, and the science buildup after Sputnik. But this time around money is tight.

Feigenbaum and McCorduck advocate the formation of a national knowledge technology lab, operating independently under federal charter. But at the moment no such institution is in view.

“If we continue as we have, [Japan and the United States] will act as guinea pigs for an interesting experiment in planned, as opposed to unplanned, research. At the moment, we Americans are placing our economic and defense bets on a method that has more or less worked for us in the past (though our current economic situation throws some doubt on its utility in a complex post-industrial world). That method, of course, is wholly decentralized planning, cutthroat competition, and a touching faith that the best will win because economic laws work that way.”

“We don’t like planning,” said Feigenbaum at a recent press conference. “It smacks of telling us what to do.” The message of The Fifth Generation—a timely one as the 1984 elections approach—is that if we Americans refuse to plan while others plan skillfully, we may like the results of not planning even less than we like planning.

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