Another classic theory—gravitational capture of the moon as it wandered by—was always too improbable to be taken seriously, but the capture of debris ripped from a planetesimal passing inside the Roche limit could not be so easily dismissed. However, Hiroshi Mizuno and Alan Paul Boss of the Carnegie Institution of Washington reported that a solid body is just too strong and stiff to lose more than 1 or 2 percent of its mass during a brief close encounter with Earth. Even a partially molten body would not disrupt, according to their calculations.

The "double-planet" theory of lunar formation, in which Earth and the moon form simultaneously from the same cloud of gas and rock, has always had the problem that the moon and Earth differ in their chemical compositions. A consortium of researchers headed by Richard Greenberg of the Planetary Science Institute pursued a variant of this model in which an existing swarm of debris retained incoming rocky material and allowed large, iron-rich planetesimals to pass into Earth, creating a batch of iron-poor material to form the moon. Unfortunately, they could not find a source of angular momentum to keep this swarm from dissipating long before its work would have been done.

Of course, the large impact hypothesis would not be so popular if, at least at first glance, it did not help explain some of the major mysteries of the moon's origin. Such a heavy glancing blow to the proto-Earth could account for the unusually large amount of angular momentum in the Earth-moon system without producing the embarrassing excess of the fission model. The contribution of rocky material from the mantles of Earth and the impactor—their mantles already having lost much of their iron during the formation of metallic cores—would explain the scarcity of iron in the moon. The heating of the disk could have driven off much of its volatile elements, which are depleted in the moon. And what little iron there was in the disk could have scavenged elements particularly compatible with it and sequestered them in a small lunar core, explaining the depletion of such elements in lunar samples.

A large impact would also meet a more philosophical need. As pointed out by Hartmann and Davis, a single evolutionary process—one that would presumably be part of the formation of every planet—would seem hard-pressed to explain the variety in satellite systems. Neptune's major satellite orbits in "reverse," Uranus's system revolves in a plane perpendicular to all others, the satellites of Earth and Pluto are large enough to be considered sister planets, Mars has two large boulders as its only moons, and Venus and Mercury have no moons at all. The sensitivity of the outcome of a planet's largest impact to everything from the impactor's size to its direction of approach might account for some of this variety.

Testing of the latest favorite theory depends crucially on the poorly understood field of impact cratering. Some work is under way to understand the biological effects of the Cretaceous-Tertiary impact and to determine the means of blasting meteorites off Mars, but this impact would have been in a class by itself.—**Richard A. Kerr**

Additional Reading

1. *Abstracts and Program for the Conference on the Origin of the Moon*, LPI Contribution 540, available for $3 ($3.50 outside the United States) from the Library/Information Center, Lunar and Planetary Institute, 3301 NASA Road 1, Houston, Texas 77058.
2. W. K. Hartmann and D. R. Davis, *Icarus* **24**, 504 (1975).
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The Fifth Generation: Taking Stock

The Japanese computer project is approaching its third birthday; meanwhile, the American programs are finally getting organized

In October 1981, at the First International Conference on Fifth Generation Computer Systems, the Japanese Ministry of International Trade and Industry (MITI) announced that it would undertake a 10-year, $850-million effort to develop advanced computers several thousand times faster than the current variety—together with software that will allow those computers to reason, to learn, to understand written and spoken language, and to generally do the things that require intelligence in a human being.

The announcement of the Fifth Generation project was not exactly a surprise—MITI officials had been talking about it since 1979—but the response on this side of the Pacific was dramatic nonetheless. After a decade of Japanese triumphs in automobiles, steel, and consumer electronics, no one was inclined to take a new challenge lightly. In short order there appeared a raft of similar programs, including the Microelectronics and Computer Technology Corporation (MCC) and the Pentagon's "Strategic Computing" program in the United States; the Alvey Program in the United Kingdom; and the multinational ESPRIT program on the Continent.

Recently, two different meetings have offered an opportunity to take stock of all this activity. In October there was the annual convention of the Association for Computing Machinery in San Francisco, subtitled, "The Challenge of the Fifth Generation"(*1*). A month later, the Japanese researchers held their 3-year review meeting in Tokyo (*2*).

It was apparent from both meetings that the activity to date has not been a horse race so much as a jockeying for position at the starting gate. The Japanese have had the planning lead, but as they freely conceded in 1981, they needed the first 3 years simply to catch up with the technologies already developed in the West.

The Americans, by contrast, have an enormous lead in technology. But they have had to spend the last 3 years scrambling to get organized. And the Europeans, caught in the middle, have been operating with a dogged determination that they will not be left behind (*3*).

Only now, in other words, does the race begin in earnest.

In one sense, the push for a "Fifth Generation" follows a long-established pattern. As Gordon Bell of Encore Computer Corporation noted in San Francisco, the history of computing technology resembles a cyclotron: every 10 years or so there comes an injection of new technology, followed by a series of refinements boosting it to higher and higher levels. For the first computers in the 1940's the major technology was the vacuum tube; later generations were based on transistors, then on integrated circuits and, starting in the late 1970's, on Very Large Scale Integration, or VLSI.

Thus, work on the newest cycle is beginning more or less on schedule. However, there are also some important differences, not the least of which is that this time around there are *two* new technologies developing synergistically. On the hardware side, the limits of microprocessor miniaturization is already in sight (albeit a good distance away); any further quantum leaps in processing power will have to involve fundamental changes in the design of computers. People are thus giving serious consideration to machines that would have thousands or millions of processors operating in parallel (*Science*, 10 August, p. 608).

And on the software side, artificial intelligence research is maturing (*Science*, 24 February, p. 802). Coupled with the advanced parallel hardware, artificial intelligence promises to produce machines that could communicate with their human users via natural language, speech, and imagery. It promises machines that can delve into massive databases, reason about the contents, and help their users extract meaningful information. It even promises machines that can partially program themselves: instead of laying out algorithms in mind-numbing detail, the user would simply tell the machine what was wanted.

Another difference in the new generation is the emphasis on cooperative research. As MCC chief scientist John T. Pinkston pointed out in San Francisco, it has become harder and harder during the last decade for individual firms to undertake long-term research on their own. And it is not just a matter of expense and risk, he said. Consider the critical mass effect: the commercial success of one new technology often depends upon the development of several collateral technologies. (Many artificial intelligence programs, for example, need parallel processors to run in real time.) So a company can either focus on one technology and hope that someone else will do the others—an approach that increases the risk—or else it can try to be like IBM and do everything itself—thereby vastly increasing the expense.

More important still, said Pinkston, is the difficulty of reaping the rewards of all that research; it is too easy for competitors to sit back and let you take the risks, and then cash in later with a copycat product.

The Japanese understand the latter dynamic very well, noted Pinkston. Their consumer electronics industry is an example of its application on a national scale. But they also have a very clear conception of technological critical mass, which was one big reason that the planners at MITI were the first to conceive of the fifth generation as an integrated system, with a coordinated, national development effort on hardware, software, *and* applications. (In fact, it was they who invented the term "Fifth Generation.")

This was not the first time that MITI had targeted an industrial sector for accelerated development, of course. The Fifth Generation project was actually part of a broad push into information technologies, under way since the late 1970's. But many Western observers also heard an unusual note of national pride in the announcement. Stanford University's Edward Feigenbaum, who was one of the originators of expert systems, and who has close ties to the Japanese, points out that MITI's 1981 planning documents were quite explicit—and quite atypical—about Japan's taking its rightful place as a world leader, shedding its copycat image, and claiming a role as a revolutionary innovator in high technology (*4*).

"Young people have fewer fixed ideas," said Fuchi.

The embodiment of that attitude was Kazuhiro Fuchi, one of the prime architects of the Fifth Generation project. As director of its central laboratory, the Institute for New Generation Computer Technology (ICOT), Fuchi stressed youth and innovation—thereby enraging many Japanese traditionalists. His 40 researchers, hand-picked from the eight corporate sponsors of the program, were all under 35. "Young people have fewer fixed ideas," said Fuchi.

The Fifth Generation plan itself was both sophisticated and comprehensive. MITI planned to commit some $45 million to the project during the first 3-year phase, during which ICOT would lay the groundwork. The rates were then to be stepped up sharply during the later phases, when extensive development engineering on the parallel systems would begin. With matching contributions from the industrial partners, the total investment would thus be some $850 million over 10 years.

Actually, although it has not been widely appreciated in the West, the 1981 plan was a product of Japanese consensus-building and was a bit *too* comprehensive. By the official opening of ICOT in April 1982, Fuchi had thrown out the kitchen-sink features and focused the research on a more realistic main line consisting of knowledge-based programming and machine problem-solving, together with the associated hardware.

According to this new plan, he has been on schedule ever since. A knowledge-based machine, built by Hitachi and Oki Electric Industry, was delivered in the spring of 1984. A logic processing machine, built by Mitsubishi Electric, was delivered in December 1983. Essentially it is equivalent to the LISP workstations used by artificial intelligence researchers in the United States and Europe. The ICOT team now has several dozen of them. At the same time, they are designing the first round of parallel machines. Says Feigenbaum, who led a delegation to the Tokyo conference in November: "Overall, things are going very well for Fuchi."

Meanwhile, the U.S. computer community's reaction to the 1981 announcement was widespread feeling that something had to be done. On 19 February 1982, 4 months after the Japanese announcement, executives of 18 computer firms gathered in Orlando, Florida, at the invitation of William Norris, president of Control Data Corporation. Norris had long been an advocate of cooperative research as an antidote to declining U.S. competitiveness in the world; now with the Japanese example serving as a catalyst, he renewed the call.

His audience was receptive. The result, after nearly a year of task forces and meetings, was the MCC. In January 1983, it was officially launched with Admiral Bobby Inman, former deputy director of the Central Intelligence Agency, as chief executive officer (*Science*, 17 June 1983, p. 1256).

The structure of MCC is strongly reminiscent of ICOT: a central laboratory staffed largely by personnel drawn from participating companies. On the other hand, MCC's agenda is much more ambitious. The consortium is taking on everything from advanced artificial intelligence research and parallel processing to the computer-aided design of the VSLI chips themselves. (The only exception is semiconductor research per se, which is being left to the Semiconductor Research Corporation, another newly formed consortium operating quietly in North Carolina's Research Triangle Park.) Moreover, MCC plans to do virtually all of its research in the central facility, whereas ICOT contracts out much of its work to its member companies. Thus, MCC is much larger than ICOT, with 220 employees to Fuchi's 40.

As a consequence, however, MCC has spent most of its young life building a staff. Inman's decision to locate the laboratory in Austin, Texas, helped considerably. Not the least of its attractions was the University of Texas, which has promised Inman that it will pour a good portion of its $2 billion oil-lands endowment into the computer-related departments. But still, it was only in the fall of 1984 that the final division director (for software development) was put in place. On the other hand, company spokesmen say that the laboratory is now essentially up to full strength, and research is moving ahead in every area.

Meanwhile, the Defense Advanced Research Projects Agency (DARPA) has been getting its $1 billion Strategic Computing program under way.

According to Robert Kahn, head of the agency's Information Processing Techniques Office, the program originated as a logical outgrowth of DARPA's 20 years as the major U.S. funding source for artificial intelligence. "We'd gotten to the point where developing the technology would take much more money than we had available in the basic research program," he says. "What we also needed to do—and what Strategic Computing would allow us to do—was to branch out of the university labs and get industry involved.

"Then when Bob [DARPA director Robert S. Cooper] arrived in 1981," says Kahn, "he and [Under Secretary of Defense for Research and Engineering Richard D.] DeLauer got behind the idea. And once the decision was made in the spring of 1982 to go forward with it seriously, they took a key role."

While Kahn maintains that Strategic Computing was not a response to Japan—"In some ways," he says, "the Fifth Generation was a response to us"—the MITI program certainly helped give the idea legitimacy. Not the least of the problems was convincing the Pentagon brass. They were used to aerospace and ordinance research, but to many of them the idea of smart computers sounded a little flaky.

The combination of Cooper, DeLauer, and Japan was persuasive, however, and in January 1983 the first request for funding arrived on Capitol Hill. Congress was willing to go along, provided only that DARPA prepare a detailed program plan before it spent any money.

DARPA's plan, prepared in consultation with researchers in the artificial intelligence community, was submitted in December 1983 (*Science*, 16 December 1983, p. 1213). It was ambitious, to say the least.

In addition to basic research in such areas as expert systems, vision, natural language understanding, and speech understanding, the plan called for three major demonstration projects: an autonomous land vehicle capable of navigating cross-country while taking advantage of available cover; a computerized pilot's associate, which would respond to spoken commands and which would help with the chores of flying the aircraft while aiding the human pilot in tactics and strategy; and a naval battle management system, which would handle the enormous information flow of a battle environment, and present relevant information to the commanders, using sophisticated graphics.

The activity has not been a horse race so much as a jockeying for position at the starting gate.

To support all this, the plan also calls for developing parallel processors that boost current computation speeds about a thousand- or ten thousand–fold.

The plan has raised some skeptical eyebrows in the research community, especially since its detailed timetables seem to demand that breakthroughs in basic research be made on schedule. But the program's chief scientist, Lynn Conway, thinks that such criticisms stem from a misunderstanding of what the program is trying to do. "We have a fair degree of confidence that we can plan and produce the autonomous vehicle hardware on schedule," she says.

But the basic research issue of perception and its relation to cognition is still very open-ended, she says. So the idea is to create a test facility where a number of the vehicles will be housed. (It will be located at the Denver plant of Martin Marietta, the prime contractor for the autonomous vehicle, and will open in 1985 or 1986.) Researchers all over the country will then have access to the vehicles through the agency's ARPANET computer network, so that they can download their programs into specific vehicles, run those vehicles around the roads and countryside of the test facility, and see what works.

"It's like the Space Telescope," says Conway. "The telescope hardware itself is planned and built on schedule. But the observations made with the telescope will be very open-ended."

The theme of industrial involvement is echoed again and again at DARPA headquarters. "It's our most important objective," says Cooper. The research means nothing to the rest of the Pentagon until there is an industrial base to provide the hardware, he says. Moreover, getting industry involved is the key to spin-offs in the private sector.

In fact, this emphasis on industrial involvement seems to have been behind one of the research community's major complaints about the program so far: namely, DARPA's handling of the Strategic Computing contracts.

DARPA, unlike ICOT or the MCC, is not a laboratory but a funding agency. Traditionally, this has meant an operating style much like the National Science Foundation's: proposals come in and, if they look good, they are funded. For Strategic Computing, however, Cooper decreed that all research contracts should go out for competitive bids. "If you want to get industry involved," he says, "then the laws are such that you almost have to do it by competitive bid."

Cynics wonder if Cooper might also have been under pressure from congressmen who sniffed the possibility of a little pork for the home state university. Be that as it may, the result was months of confusion and heated tempers, while artificial intelligence researchers tried to figure out how to write such bids, and while the people in Kahn's office got organized to evaluate them.

By now, says Kahn, the problem has largely worked itself out. The bidding has closed, more than a dozen contracts have been awarded, and others are on the way. "We've gotten organized, and we've given shape to the long-term program," says Kahn. "We expect in 1985 that we'll take off."

In sum then, it seems that the American and Japanese Fifth Generation programs enter 1985 in rough parity. In San Francisco, the speakers gave all of them high marks for a good beginning. But only in the next few years will we start to see how realistic the plans really are.

—M. Mitchell Waldrop

References

1. The 1984 Annual Convention of the Association for Computing Machinery, 8 to 10 October, San Francisco.
2. The Second International Conference on Fifth Generation Computer Systems, 5 to 8 November, Tokyo.
3. The remainder of this article will focus on the Japanese and American programs. The Alvey project has been covered in *Science*, 20 May 1983, p. 799; ESPRIT in *Science*, 6 January 1984, p. 28.
4. E. A. Fiegenbaum and P. McCorduck, *The Fifth Generation* (Addison-Wesley, Reading, Mass., 1983).