these synchronizations determines at which grain size parallelism can be exploited effectively. Fine-grained parallelism, for instance, requires frequent synchronization, usually after executing one or only a few instructions. Therefore, the synchronizations must be cheap. On the other hand, synchronizations in coarse-grained parallel applications are much less frequent. As a result, these applications can tolerate higher synchronization overheads.

FURTHER READING

Culler, D. E., J. P. Singh, and A. Gupta. *Parallel Computer Architecture, A Hardware/Software Approach.* San Francisco: Morgan Kaufmann, 1999.

Foster, Ian. *Designing and Building Parallel Programs: Concepts and Tools for Parallel Software Engineering.* Reading, Mass.: Addison-Wesley, 1995.

Fox, Geoffrey C., R. D. Williams, and P. C. Messina. *Parallel Computing Works.* San Francisco: Morgan Kaufmann, 1994.

Hwang, Kai, and Zhiwhei Xu. *Scalable Parallel Computing: Technology, Architecture, Programming.* Boston: WCB/McGraw-Hill, 1998.

Kumar, Vipin, et al. *Introduction to Parallel Computing: Design and Analysis of Algorithms.* Redwood City, Calif.: Benjamin-Cummings, 1994.

—Andy Pimentel

Parametron Computer 1

The Parametron Computer 1 (PC-1) was developed and built at Hidetosi Takahasi's Laboratory at the University of Tokyo in 1958. It was one of the first Japanese computers and is especially remembered because it used logic elements capable of computing majority logic, called *parametrons*. Parametrons are doughnut-shaped magnetic elements that work by combining the fields induced by cables coiled around the cores.

The initial impulse for the development of the PC-1 in Tokyo came from careful study of the architecture of the **EDSAC** computer built at Cambridge, but the Japanese then adopted a new approach regarding the logical structure of the machine. Conventional logic elements deal with one or two bits a time, and compute operations such as conjunction (AND), disjunction (OR), and negation (NOT). The Japanese adopted *threshold logic*, in which elements deal with several bits at a time, posing the question: Is the number of 1's in the input larger than a certain threshold? A threshold **logic gate** with five 1-bit inputs and the threshold 2 can then be used to ask if the majority of the five bits are 1s. The threshold *logic gate* produces a 1 if this is the case; otherwise, the result is 0.

It is easy to see that threshold gates include as a special case the conventional gates. The AND operation with two bits corresponds to a parametron with two 1-bit inputs and threshold 2. Only if both bits are a 1, the parametron "fires" a 1. The OR operation corresponds to the same arrangement but with a threshold of 1. If any of the two bits or both are 1, the parametron fires a 1, otherwise a 0. Negation was implemented in a special way in the parametrons, by using a cable coiled in reverse direction, which reduced the magnetic field induced by other inputs.

Threshold logic computers can be built using a much lower number of gates than for conventional machines and, in some cases, less than one-third for equivalent machines. Some parametron designs were built in Japan, but the cost of the individual gates is greater than that for standard gates. Therefore, no successful commercial threshold computers have ever been built.

The PC-1 was an interesting machine also in regard to the software that it used. The systems programmer, Eiiti Wada (1931–), achieved the feat of writing a start routine for the computer with the instructions arranged such that a conversion table was embedded in the code. The same memory area could thus be used for two different purposes, according to the execution context. The PC-1 is also notable for having been one of the first computers to implement **interrupts**.

The original development team still meets once every year in Japan to celebrate the "birth" of the PC-1, a unique machine in the history of computing.

FURTHER READING

Takahasi, Hirosi, ed. *Parametron Computers.* Tokyo: Iwanami Shoten, 1968 (in Japanese).

Wada, Eiiti. "The Parametron Computer PC-1 and Its Initial Input Routine." In Raúl Rojas and Ulf Hashagen, eds., *The First Computers: History and Architectures.* Cambridge, Mass.: MIT Press, 2000.

—Raúl Rojas