MODERN COMPUTER CONCEPTS

Joseph C. Giarratano

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by

Joseph C. Giarratano, Ph.D

Howard W. Sams & Co., Inc.
4300 WEST 62ND ST. INDIANAPOLIS, INDIANA 46268 USA

Joseph C. Giarratano received his B.S. and M.S. degrees in physics from California State University at Los Angeles. In 1974 he earned his Ph.D. degree in physics at the University of Texas at Austin.

Dr. Giarratano has worked in the field of medical physics with interests in the applications of computers to medicine. He was also appointed an adjunct clinical professor of radiology at the Medical College of Wisconsin, certified as a radiological physicist by the American Board of Radiology, and elected a Member in Physics by the American College of Radiology. During this period he wrote this four-volume series on computer technology.

Dr. Giarratano now works in the area of software development for microprocessor-based products at Bell Laboratories. He is also on the faculty of Martin Center College in Indianapolis and teaches computer technology there.

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PREFACE

This is the second book of a four-volume series about computer technology and BASIC programming concepts. The material in this volume builds on the fundamentals established in *Foundations of Computer Technology*, the first volume in the series.

The material covered in this book includes a discussion of the most important features of modern computer technology:

- Memory technologies and types, such as RAM, ROM, PROM, EPROM, and CCD.
- The central processor unit and modern architectures; also microprocessors and microcomputers.
- Magnetic memories, including tape, disk, and bubble.
- Data communications.
- Computer networks and architectures.
- Videotex and the coming revolution in home information systems.
- Guide to purchasing a computer system, comprising about 80 questions a prospective buyer might ask a vendor.

The book is designed to acquaint you thoroughly with the hardware systems in use in the 1980s and to help you adapt to the information handling and processing opportunities you will encounter.

Please note that it would be impossible to include descriptions of hardware and software products from all manufacturers in these volumes. Products were selected as being representative examples of those currently being manufactured. No claim is made or implied in these volumes that any company's products are better than any other company's. The inclusion of any product does not constitute an endorsement by the author or the publisher. Nor does the absence of any product from these volumes imply any criticism by the author or the publisher.

JOSEPH C. GIARRATANO

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J.C.G.

This book is dedicated to my parents.

CONTENTS

1 MEMORY DEVICES

While the CPU receives the glory, it is memory which is most responsible for the computer's cost, speed, and reliability. Even though modern IC technology has allowed development of a single-chip microcomputer, there are many applications that require more memory than present technology can put on a single chip. Consequently, more memory chips are needed to obtain the desired amount of memory. But, as the number of chips increases so does the amount of printed circuit board space, interconnections, power, and design time needed. All of this increases the cost and decreases the computer's reliability since more components can fail. So, the more components we get on a chip, the fewer chips we need for a given amount of memory.

The obvious solution, then, is to put more on each chip. This has been successfully done by increasing the number of components on an IC, and also decreasing the width of the lines (taking the place of wires) that interconnect components. In the last two decades, IC component size and line width have decreased considerably, and this trend is still continuing. For example, common line widths for commercial ICs have decreased from 10 to 2 micrometers between the 1960s and the 1980s. Table 1-1 summarizes the line widths used with different IC technologies in the 1960–1980 time period. As line widths have shrunk, the number of components on an integrated circuit has increased. Also, the use of polysilicon signal lines separated by oxide has allowed the burying of a signal line within the chip, while the use of only metal for interconnections has allowed just a surface layer of connections to be maintained. Double and triple buried polysilicon layers have allowed more layers of circuits to be built up, which has further increased component density.

The reduction in size that contributed to increased density was called *scaling.* This involved the reduction of line widths, voltages, oxide thickness, and other parameters of existing designs to produce a smaller circuit requiring less power and giving faster operation. Fig. 1-1 specifies the physical size (1 mil = 0.001 inch) for two erasable programmable (EPROM) chips. The acronym, HMOS, which stands for *high-performance MOS*, is Intel's designation for their scaled process.

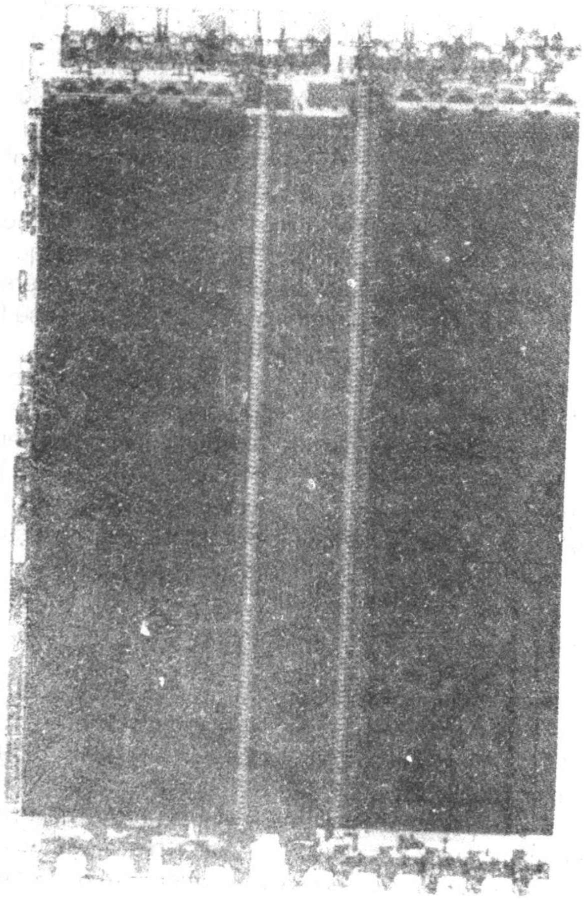
EVOLUTION OF MEMORY

The dramatic appearance of single-chip microprocessors in the 1970s was a revolutionary change for the CPU. However, the progress for memory chips in the same era was evolutionary rather than revolutionary. From a 256-bit chip in 1969, gradual improvements in memory chips led to a 1K, 4K, 16K, and then a 64K chip RAM over the next 10 years. Table 1-2 summarizes some features of RAM chips in this period. Most of the memory chips are ×1 or single-bit types. That is, with a 4K × 1 chip, it would take eight to make a 4K-byte memory since there are 8 bits per byte. Likewise, for a mainframe computer with a 60-bit word, it would take 60 4K × 1 chips to make 4K of 60-bit words.

Putting a lot of chips on a circuit board was not a problem for mainframe designers since they were used to large machines. However, it was a problem for small microcomputer designers trying to keep the cost down. The mainframe and minicomputer designers expected to sell a modest quantity of computers for medium to expensive prices. However, microcomputer sales depended on a large volume at a low price. Because the IC technology of the early 1970s could produce only low-density memories, the 1-bit wide designs were most common. Later

Table 1-1. Evolution of IC Fabrication

	1960	1965	1970	1975	1981
Leading technology	Discrete devices	Small- and medium-scale integration	PMOS	NMOS	Scaled MOS
Line width (micrometers)	10	7–9	5–8	3–5	2
Interconnect technology	Metal on top	Metal on top	Metal on top and one layer of polysilicon	Metal and one or two buried polysilicon layers	Metal on top and one, two, or three polysilicon layers



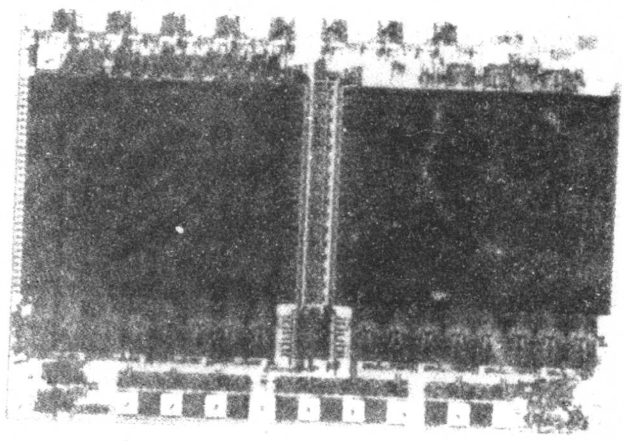


Fig. 1-1.
A comparison of NMOS and HMOS chips shows the effect of scaling down on the size of ICs. (*Courtesy Intel Corp.*)

Table 1-2. Evolution of RAM Chip Characteristics

Year	Part	Configuration	Die Area in Mil² k = 1000	Size Dimension in Mils	Access Time
1970	1103	1K × 1 Dynamic	15.7k	113 × 139	350 ns
1973	4096	4K × 1 Dynamic	28.1k	150 × 187	350 ns
1974	4096	4K × 1 Dynamic	18.7k	127 × 147	250 ns
1976	4027	4K × 1 Dynamic	20.1k	165 × 122	200 ns
1976	4027	4K × 1 Dynamic	14.6k	104 × 140	150 ns
1976	4116	16K × 1 Dynamic	27.7k	122 × 227	150 ns
1977	4027	4K × 1 Dynamic	11.9k	96 × 124	120 ns
1977	4116	16K × 1 Dynamic	22.3k	110 × 203	120 ns

improvements in technology provided higher density designs that allowed efficacious 4- and 8-bit wide IC memories. The introduction of byte-wide chips, such as the 8K × 8, resulted in a chip which was much more convenient and economical for small machines. Now an 8K-byte microcomputer memory could fit on one chip, greatly decreasing overhead costs such as board space, interconnections, and power.

Another characteristic that continuously decreased in this period was the memory access time. This is the time needed by a memory to respond with output data upon command by the CPU. Access time is the same as read time. However, write time may not be the same as read time. From Table 1-2, it can be seen that the memory access time improved by about three times between 1970 and 1977. Other significant reductions were effected in price and power consumption, and reliability increased. System design was made easier by chips designed to operate from a single +5-volt supply instead of three voltages: +12 V_{DD} (drain voltage), +5 V_{CC} (collector voltage), and −5 V_{BB} (body voltage).

MEMORY TYPES

There are a number of characteristics used to describe memory such as speed, power consumption, cost, and so forth. Another is to categorize memory as semiconductor type or magnetic type. Today, semiconductors are used for short-term storage of data in the computer's main memory while magnetic memory types such as disk and tape are used for long-term mass storage.

Another important characteristic of a memory type is its *volatility*. Data in a *volatile* memory behaves like a volatile substance—unless controlled, it tends to disappear. When the voltage or power to a volatile memory is turned off, the contents are lost. This is characteristic of most semiconductor RAM. In contrast, the contents of magnetic memory such as disk, tape, and bubble are not lost if the power is removed. However, the access time of magnetic media is 10 or more times longer than semiconductor. Thus, semiconductors are used for the computer's fast main memory, while magnetic materials are used for slower, serial long-term storage. Semiconductors also cost more per stored bit than magnetic media, so the magnetic types are used for economical mass storage.

There are also semiconductors with nonvolatile storage capability. However, it is not as easy to both read and write with them as with the magnetic type. In fact, some of the nonvolatile semiconductors can only be read from and they are called read-only memory (ROM). In this chapter, we examine the semiconductor types and cover magnetic memories in Chapter 3.

Fig. 1-2 illustrates the general classifications of semiconductor memory that we will examine in the following sections. Note the acronyms for each class. As you will see, the electronics industry is fond of acronyms. Advertisements and technical papers are sprinkled with an "alphabet soup" of terms such as RAM, ROM, PROM, EPROM, EEPROM, EAROM, and many others. It is important to know what these stand for. Otherwise, you may get an unpleasant surprise if you put 16K of ROM into a computer and expect it to act like 16K of RAM.

Use of the memory devices in Fig. 1-2 can be summarized by an example of program development:

1. The program is developed in RAM, which might be in a host mainframe, a mini, a micro development system, or even the target computer itself.
2. The program is copied to EPROM or EEPROM. This allows the designer to see what the final memory device for the target will be like. Yet, it also facilitates program modification due to any remaining bugs. Another advantage is that the EPROM and EEPROM are nonvolatile memories; that is, their contents will not be lost if power is removed, as is the case with RAM.
3. The final version of the program can be put in PROM or ROM. the ROM is suitable for the large volume production of chips and must be done in a

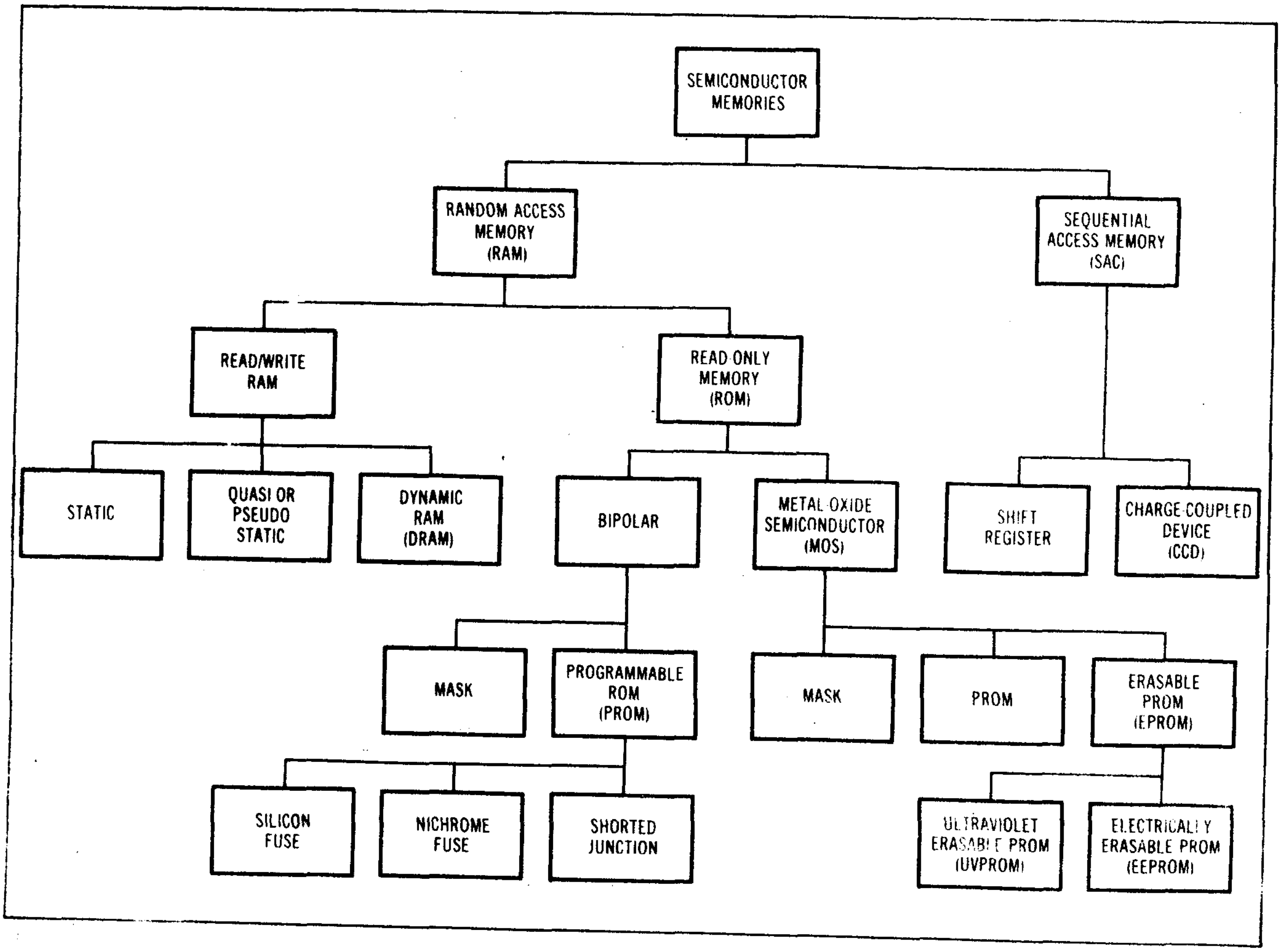


Fig. 1-2.
Types of semiconductor memories.

• factory. The PROM is more economical for smaller runs or customizing the program for different users.

Figs. 1-3 and 1-4 summarize cost, speed, and capacity of various storage media. Fig. 1-3 relates the end-user price to the storage capacity of different memory systems. The end-user is anyone who acquires a computer for their own use and not for resale. This is in contrast to an original equipment manufacturer (OEM) who purchases components or complete computers for sale to others. Fig. 1-3 shows price ranges for different types of memory. As you can see, larger amounts of memory cost less per unit purchased. Fig. 1-4 shows the cost vs. time to access different types of memory. Bubble memory fills what is called the *access gap* present with other types of memory, where no others had been able to adequately fill the gap of access times in the range 1.0 μs–10 ms.

RANDOM ACCESS MEMORY

Ideally, the memory cells of a RAM are organized so that the access time for any element is the same as any other. This can be approximated by arranging the cells in a two-dimensional array. In a real chip, the access time of a cell may depend to some extent on its position.

Array Addressing

Any cell can be accessed by supplying the appropriate address and control signals. The address signals are supplied by the CPU over the address bus and

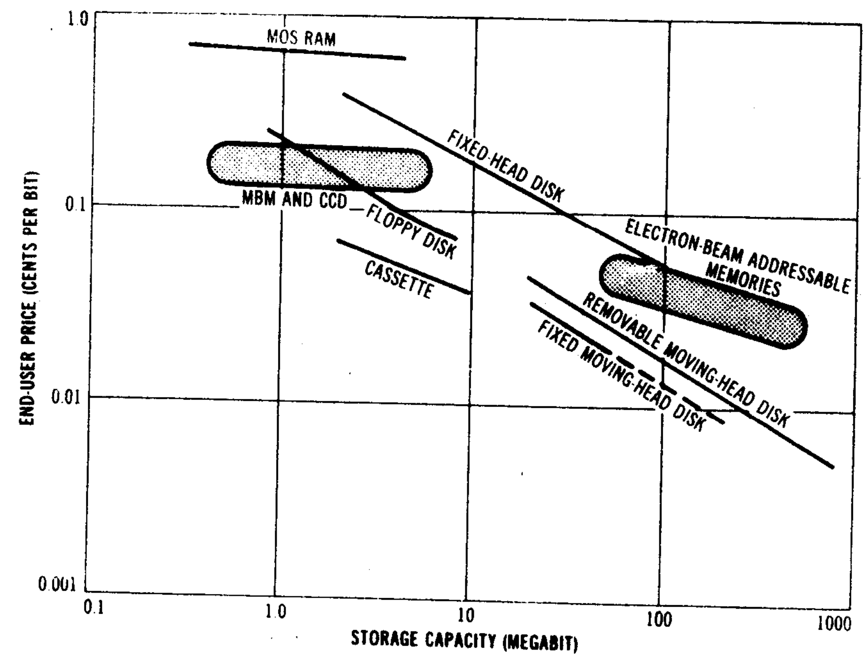


Fig. 1-3.
A comparison of cost and storage capacity of various media. (*Reprinted with permission from* "CCD and Bubble Memories: System Implications," *by Dean R. Toombs*, IEEE Spectrum, *May 1978*)

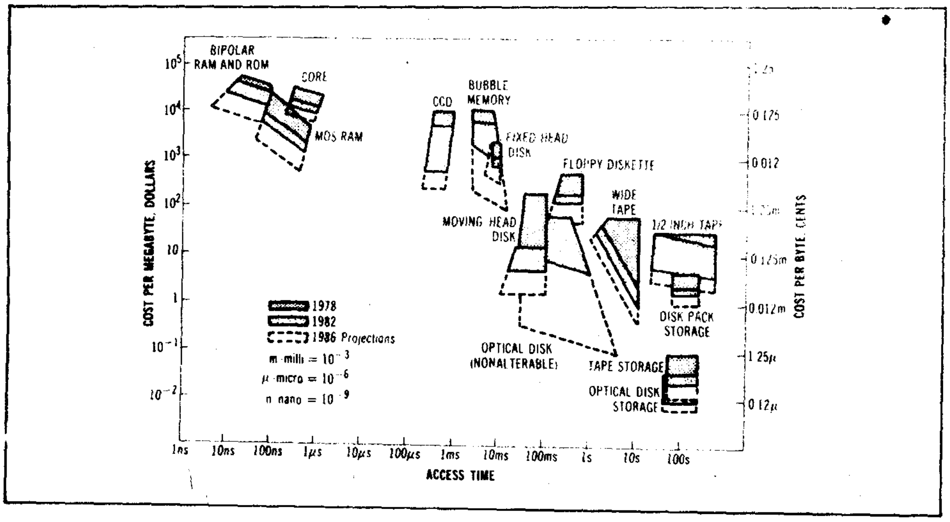


Fig. 1-4.
A comparison of cost and access time of various media. (*Reprinted with permission from* "Higher Densities for Disk Memories," *by Chao S. Chi*, IEEE Spectrum, *March 1981.*)

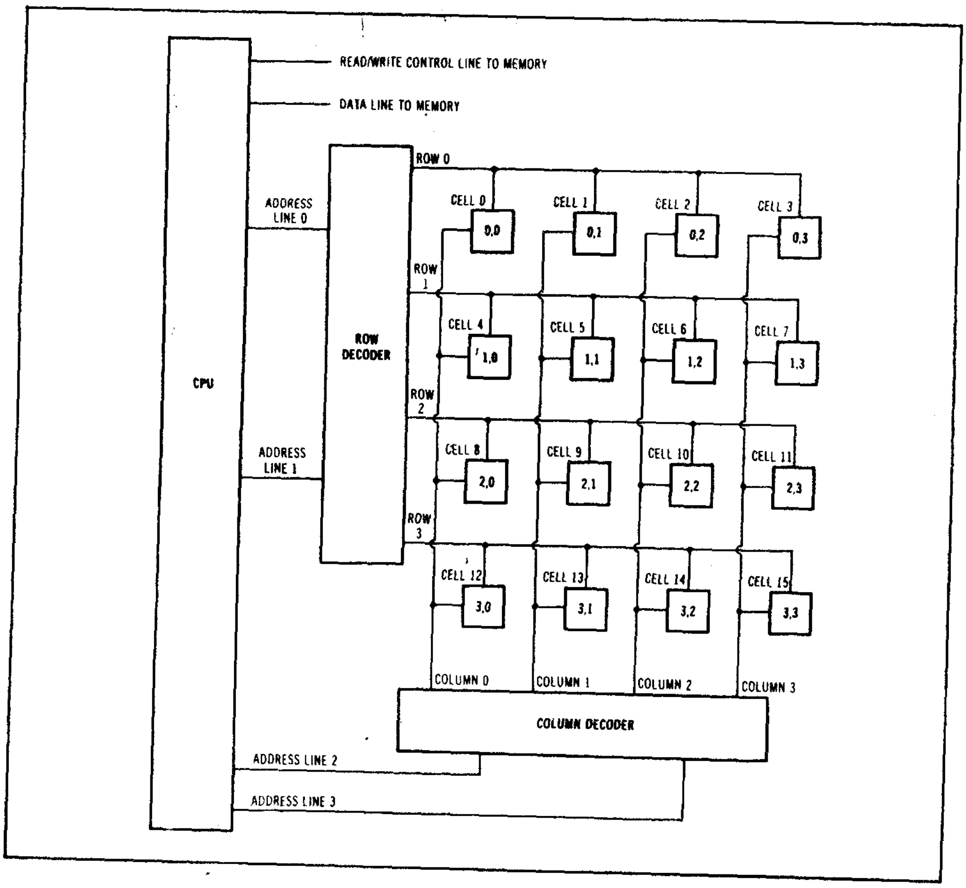


Fig. 1-5.
Random access lines for a 16-cell memory.