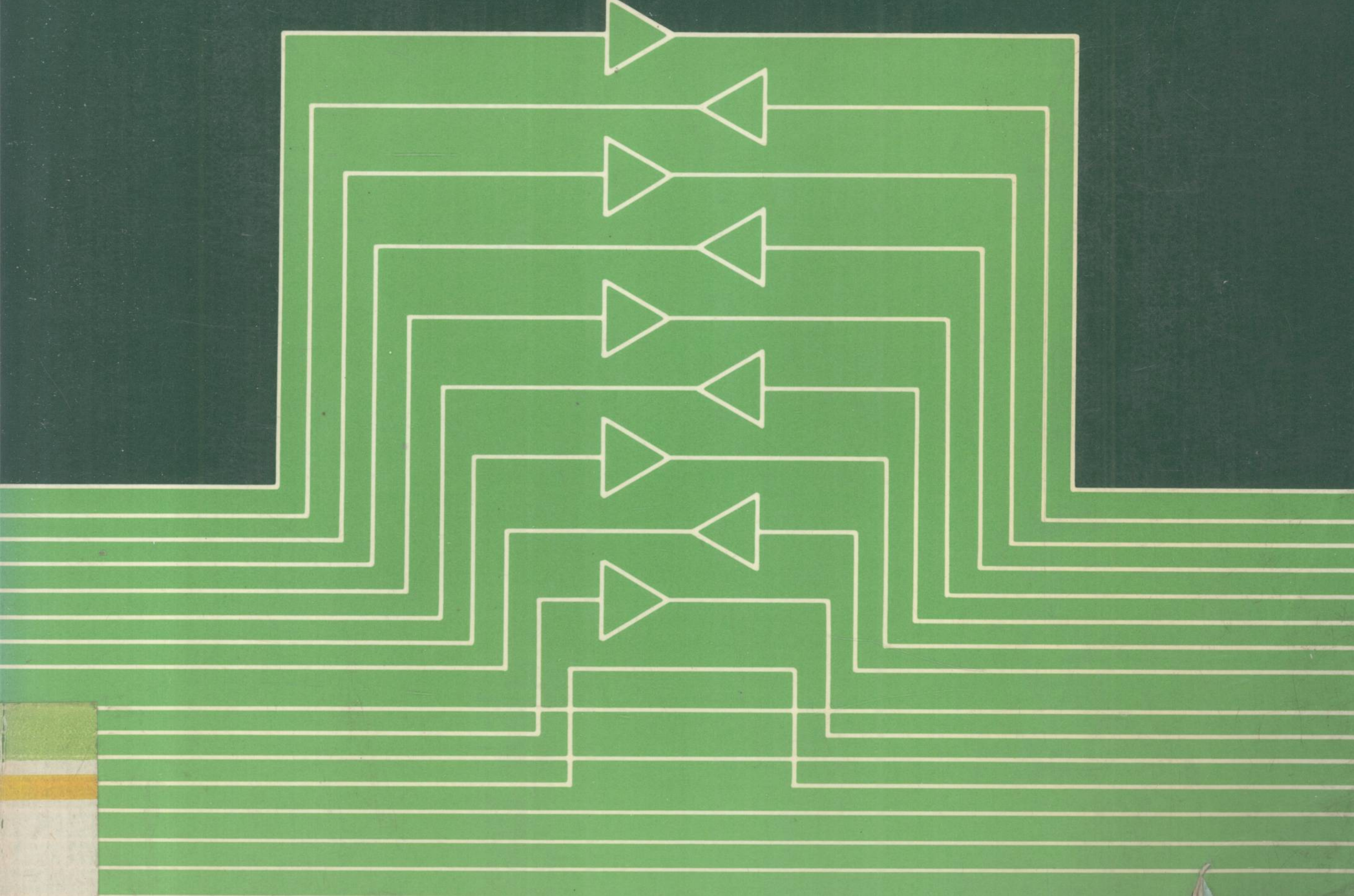
THE 68000 MICROPROCESSOR

Andrew M. Veronis



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Andrew M. Veronis, Ph.D.
Professor
Department of Electrical Engineering
Howard University
Washington, D.C.

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This book is dedicated to my dear mother-in-law Eleanor Hough Buckler, for all the love and kindness she has shown me.

Preface

The Motorola MC68000 family of microprocessors is undoubtedly a revolutionary set of devices. The MC68000 is the first advanced 16-bit microprocessor with a 32-bit internal architecture and the first with 16-megabyte, nonsegmented, direct memory addressing. The processor's six basic addressing modes are equivalent to 14, when one considers all of the variations among these modes. Combined with the device's data and instruction types, the modes provide more than 1000 useful instructions.

The book you are about to study has been developed as an aid to the hardware designer and as a supplement to the Motorola seminars on the 68000 microprocessor. The text includes a detailed description of the MC68000 and two complete systems that show how this processor can be interfaced to the outside world.

The book follows a "top-down" approach. A brief history of microprocessors is provided first. Chapter 2 details the MC68000 by describing its registers, control lines, and capabilities.

Chapter 3 introduces a small MC68000-based system. Although this system is characterized in the book as hypothetical, it is indeed the Educational Computer Board, used in the various Motorola seminars.

The addressing modes and instructions are explained in Chapter 4, which includes helpful hints on how instructions can be used. Chapter 5 provides an in-depth description of additional instructions and numerous examples.

Chapter 6 discusses exception handling and interrupts.

Chapter 7 describes how the MC68000 processor can be connected to eight-bit and 16-bit peripheral devices. This Chapter also covers the interfacing of the Motorola Educational Computer Board to a terminal, a modem, a printer, and a cassette interface. Various interfacing programs are listed in this Chapter.

Chapter 8 provides full description of a second MC68000-based system, the VU68K. This system was built initially by students of the Computer Science Department of Vanderbilt University, and subsequently has been constructed by some of the author's students. The most interesting part of this Chapter is the detailed description of an operating system monitor, the VUBUG. Study of the VUBUG provides the reader with valuable experience in the use of the MC68000 instructions, as well as in the design of a basic, but fully functional, operating system monitor.

The writing and production of a book really involves many people, such as reviewers, copy editors, and artists. Perhaps the only chance that an author has to thank these people is through the preface of the book.

I wish to thank everyone who participated in the production of this book. I particularly wish to thank my friend Joe Gordon for helping me with the illustrations.

Most authors use the preface of their book to thank their loved ones for their patience. I wish to do the same, to thank my dear wife Elizabeth Veronis not only for her tremendous patience but also for her active participation in the typing and editing of the manuscript. Her help has been invaluable.

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Andrew M. Veronis
Annapolis, Maryland

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Chapter 1
Basic Concepts

BRIEF HISTORY OF MICROPROCESSORS

The first two microprocessors—the 4004 (a four-bit set of devices) and the 8008 (an eight-bit device on a single chip)—were produced in the early 1970s by a newly formed company, Intel Corporation. The 4004, also known as the MCS-4, was designed to replace six custom chips in a desktop calculator and was therefore programmed for serial, binary-coded, decimal arithmetic (a very common practice in handheld and desktop calculators). Although the client, a Japanese manufacturer named Busicomp, went out of business before it could put the 4004 to work, this set of devices was soon adapted for numerous other applications.

A U.S. company named Computer Terminal Corporation (also known as Datapoint) similarly requested Intel to design a push-down stack chip for a processor to be used in a CRT terminal. Datapoint intended to build a bit-serial processor in TTL logic with a shift-register memory—a design that would require a fair number of devices. Intel suggested that the entire design could be implemented in one chip. This new processor was the 8008. Although Datapoint eventually did not use the chip because of the long lead time Intel required, the device was quickly adopted by other logic design engineers, who saw the advantages to be derived from microprocessors.

At about the same time, Motorola, Texas Instruments, Zilog, and other semiconductor manufacturers were gearing up to capture a share of what was to become the largest semiconductor market. Improved devices such as the Intel 8080 (second-sourced by other manufacturers, including Texas Instruments and National Semiconductors), the Zilog Z80 (the most popular eight-bit processor ever marketed), and the Motorola 6800 (also an extremely popular eight-bit microprocessor) have dominated the market for more than a decade.

As the benefits of microprocessors became more apparent, design engineers and, more particularly, programmers increasingly demanded better performance. Eight-bit microprocessors are designed to replace logic circuits and, consequently, emphasize controller-type capabilities rather than ease-of-programming elegance. Compare, for example, the instruction format of an eight-bit processor to that of a 16-bit device, as shown in Fig. 1-1.

Clearly, an eight-bit processor lags behind in the available number of registers, instructions, and addressing modes, as well as the memory addressing range. All

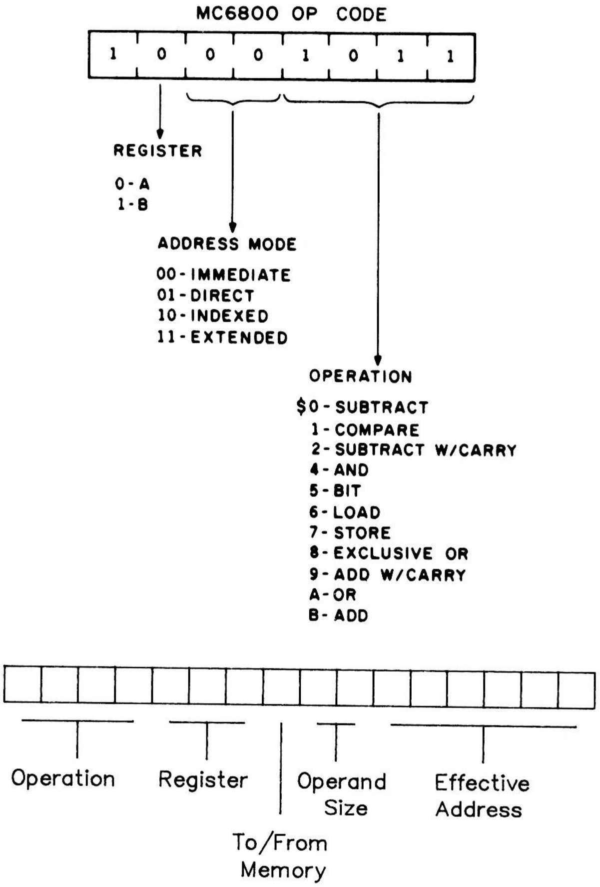

Fig. 1-1. Formats of 8-bit and 16-bit instructions.

of these features are needed for efficient programming. Thus, eight-bit processors gradually are giving way to 16-bit and 32-bit processors.

DESIGN OF A MICROPROCESSOR

Design Considerations

Numerous factors affect the overall performance of a microprocessor system, including internal organization, speed, instruction set, addressing modes, memory-handling capacity, interfacing ease, and availability of compatible peripheral devices. The system designer must consider them all.

Some of these factors will be described in the following pages. To facilitate this description, a powerful 16-bit processor—the Motorola MC68000—will be referred to from time to time. This device will not be examined in detail, however, until Chap. 2.

Registers

One significant advantage of a 16-bit microprocessor over an eight-bit device is that the former has twice the word width; as a result, a 16-bit device can handle twice as much information, thus increasing the processing speed of a system. Another advantage is the increased number of internal registers this device provides the programmer. The MC68000 excels in both of these areas.

As shown in Fig. 1-2, the Motorola MC68000 has eight 32-bit data registers, nine 32-bit address registers (registers A7 and A7′ are the user and supervisor stack pointers), and a 32-bit program counter (although the maximum address range is 24 bits). Since most of its data and address registers are undedicated, the MC68000 thus provides greater flexibility.

Addressing Modes

Having a good number of addressing modes is likewise an advantage for a microprocessor. The MC68000 has 15 addressing modes. With few exceptions, each instruction operates on bytes, words (16 bits), and longwords (32 bits), and most instructions can use all 15 modes.

One weakness of an eight-bit microprocessor is its limited memory-accessing capacity. With a 16-bit address bus, this device can directly address only 65,536 addresses. Some schemes increase the address range of an eight-bit processor, or so it seems. For example, Fig. 1-3 illustrates a method called *paging.* In this scheme, the total memory area is divided into pages. Although the 16-bit address range remains unaltered, bits in another register, such as the program counter, are used to designate the number of the page. Theoretically, this practice

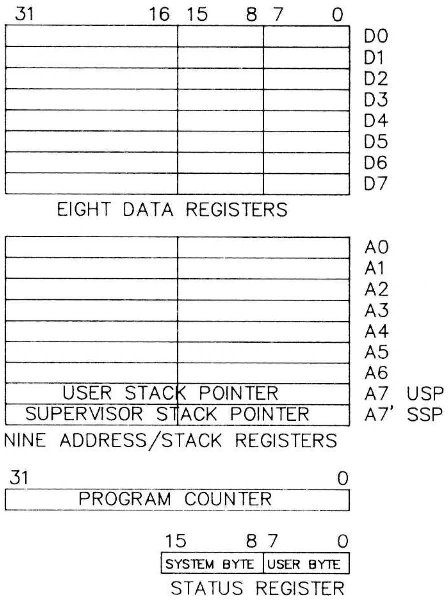

Fig. 1-2. MC68000 registers.

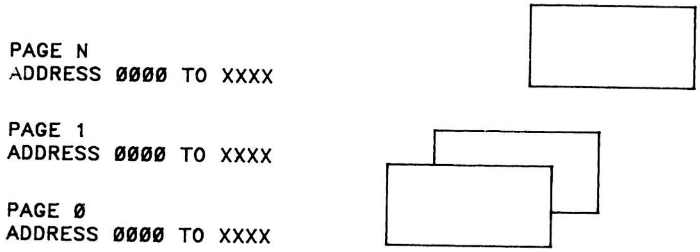

Fig. 1-3. Memory paging.

increases memory capacity, but it is dependent on the bits allocated to designate page numbers. Although the addition of several page registers will eliminate the problem of page bits, paging is still limited by the fact that only a single page can be accessed at a time. This method is tricky, moreover, and time-consuming.

To overcome the deficiencies of paging, some 16-bit microprocessors use a method called *memory segmentation.* Since the memory spectrum is divided into segments, this method is similar to paging, as Fig. 1-4 shows. A segment number added to the 16-bit address identifies each segment. Segmentation allows some possibility of address relocation, but the size of each segment is a limiting factor (it cannot exceed 64 kilobytes), and the desired segment must be loaded as well.

The most straightforward method of memory accessing is called *linear accessing.* Simply speaking, a processor with linear addressing capabilities has adequate address lines to access memory directly. For example, the 23 external address lines of the MC68000 allow direct access of 8.4 million words of memory. Since programmers are always hungry for more memory, however, provisions have been made to carry out a type of paging with some control lines furnished by the MC68000. This method will be explained later. Furthermore, memory management devices can be used with the MC68000 to provide additional memory capacity.

Prefetch

A significant factor in the selection of a microprocessor is the manner in which a particular device fetches instructions from memory. After an eight-bit microprocessor fetches an instruction, the address- and data-fetching circuits and buses of

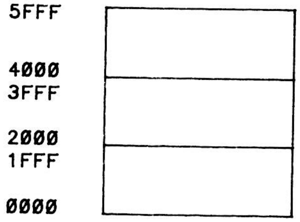

Fig. 1-4. Memory segmentation.

the device remain idle while the instruction is being executed. Needless to say, this represents a loss of time. The MC68000, in contrast, has a *prefetch queue.* During the execution of one instruction, the device fetches a number of other instructions and aligns them in the prefetch queue. Consequently, the microprocessor nearly always has an instruction available for processing. This instruction is stored in close proximity to the arithmetic-logic unit (ALU).

Multiple Arithmetic-Logic Unit

A system designer also must consider features that will increase the processing speed of a microprocessor. All eight-bit microprocessors feature only a single arithmetic-logic unit, and this is used both for data processing and for calculation of addresses. In a processor that uses indexed addressing, the offset value must be added to an address via this single ALU at a time when data could otherwise be processed.

In contrast, the MC68000 uses not only a 16-bit-wide ALU as the main data-processing mechanism but also two other 16-bit ALU to function in parallel as a 32-bit ALU for the calculation of addresses. Thus, at the same time a 16-bit datum is being processed, the address ALU can be calculating an effective address (this term will be described later). The 16-bit data ALU also is used to process 32-bit values by taking two passes at 16-bit data, one for the lower word and one for the upper.

Microprogramming

All eight-bit and most 16- and 32-bit microprocessors are designed as **hardwired logic** units—i.e., the control unit is built of logic gates permanently wired to each other. This design eliminates excessive use of components and improves speed on the one hand, but, on the other, not only reduces the flexibility of the control unit but also overcomplicates the design of a complex unit.

Microprogramming of a complex control unit simplifies design by making the unit modular; that is, each section of the unit may be modeled, built, and tested independently. Additionally, a microprogrammed design permits a customer to make design changes (although the MC68000 uses a microprogrammed design, Motorola is rather reluctant to implement a customer's microcode into this design).

Peripheral Devices

To compete successfully, a manufacturer embarking on the design of a microprocessor must provide an entire family of peripheral devices. Design and production of such devices are frequently very expensive and time-consuming. Concerned with the possible loss of their share of the microprocessor market, several manufacturers have introduced microprocessors without peripheral devices. Motorola chose to add several control lines to the MC68000 to make it directly compatible with the readily available peripheral devices from the MC6800 family. This