16/32-BIT MICROPROCESSORS 68000/68010/68020

Software, Hardware, and Design Applications

WUNNAVA V. SUBBARAO

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To the respectful memory of my professors

Dr. Earnest Anderson, Ph.D., P.E., North Dakota State University, Fargo, and

Dr. S. Jnanananda, Ph.D., D.Sc., Andhra University, Waltair, Andhra Pradesh, India, for their perseverance, compassion, and interest in my education,

and

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PREFACE

In recent years, the single most important development in the field of digital electronics has been the microprocessor. Thanks to VLSI (very-large-scale integration), it has grown from the simple 4-bit processing element of a quarter-century ago to the complex 32/64-bit processing unit of the present time.

The Intel and Motorola corporations have been leaders in the development of microprocessors and associated electronic circuits. Currently, the two frontrunning families of microprocessors are the Intel 8086/186/286/386 family and the Motorola 68000/10/20/30 family. The Intel processors are very popular in such personal computers as the IBM PC and compatibles. The Motorola processors are equally popular in such personal computers as Apple's Macintosh, Commodore's Amiga, and Atari's ST. Most industrial controllers and systems, such as image-processing systems, robotic systems, and communication systems, are based on the Motorola 68000 family.

This book focuses on the Motorola family of microprocessors. It is written as a college-level text for electrical engineering and technology students, computer engineering and technology students, and computer science students. It can also serve as a self-teaching text for practicing engineering and technical personnel.

The book examines general software and hardware concepts of microprocessors, as well as microprocessor-based system design and implementation schemes, with specific reference to the 68000 family of processors. Descriptions of the software and hardware are sufficiently detailed to enable the reader to make use of the concepts in practical applications. Most of the software and hardware discussions are based on actual working models.

The 68000 family consists of the 16-bit 68000 processor, the 8-bit 68008 processor, the 16-bit virtual memory 68010 processor, the enhanced virtual memory 68012 processor, the 32-bit cache memory 68020 processor, and the 32-bit enhanced cache memory 68030 processor. All of the later versions are based on the original 68000. Coverage of the text includes the architecture, software, hardware, and application details of the 68000 processor, with concepts extended to the other family members. Assembly programming techniques, parallel and serial I/O (input/output) interface techniques and associated applications, interrupt and DMA (direct memory access) applications, and system implementation schemes have been given particular emphasis.

Chapter 1 presents the basic concepts of the 68000 family of microprocessors and introduces the architecture of the 68000. The special features of the 68000 family are also described. In **Chapter 2** the memory organization schemes, data structures, and addressing modes associated with the 68000 are covered, along with the instruction format and structure typical of the 68000 family. The instruction set of the 68000 is presented in **Chapter 3,** with particular emphasis on the general flow of the instruction structure, the instruction timing, and the instruction groups.

Chapter 4 deals with software and programming techniques and applications of the 68000 processor. Assembly programming methods and special software features such as macros are examined in detail. The important aspect of exception processing is covered in **Chapter 5.** In this chapter, exception processing resulting from interrupts and error conditions is described.

Chapter 6 deals with the hardware structure of the 68000 processor and the interfacing techniques with the memory and I/O. Important hardware concepts, such as address decoding, read and write bus cycle timing, and the VME and VERSA busing schemes, are introduced. This provides a foundation for the discussion on the parallel I/O interface to the 68000 and associated applications in **Chapter 7.** Important parallel interface devices, such as the 6821 PIA and 68230 PI/T, are introduced in this chapter. Data entry and display applications and position control using stepper motors are presented, along with hardware and software details. This leads to a description of the serial I/O interface to the 68000 and associated applications in **Chapter 8.** Industry standard serial interface devices, such as the 6850 ACIA and 68901 MFP, are introduced. RS-232 serial data communication and coded data transmission applications are presented, including hardware and software details.

Chapter 9 deals with the most important aspects of the interrupts and the DMA (direct memory access) schemes associated with the 68000. Such practical applications as the daisy chain of interrupts, interrupt-driven gain controllers, and interrupt-driven data-acquisition systems with A/D and D/A are presented, again with hardware and software details. General concepts of the DMA are presented through a practical application using DMA-based high-speed data transfers.

Chapter 10 introduces the 68010 virtual memory processor. The general concepts of virtual memory, virtual machines, and the operating system are discussed in detail. The additional resources of the 68010 and 68012 processors are also covered, along with memory-access fault correction schemes using virtual memory concepts.

In **chapter 11** the 32-bit 68020 and 68030 cache memory processors are introduced. The concepts of cache memory organization are discussed. Additional resources of the 68020 and 68030 processors and related performance improvements are presented. An objective comparison between the 68000 and the 68020/30 is also included to provide insight into the applications of these very powerful processors.

Finally, the book includes four appendices: Appendix A on number systems, Appendix B on the 68000 instruction set and condition uses, Appendix C on analog and digital converter devices for interfacing, and Appendix D on instruction timing for the 68000/10 processors.

The material is designed to be used in a two-semester course. For engineering and technical students, Chapters 1, 2, 3, 4, 5, and 6 can be covered in the first semester. In the second semester, Chapters 7, 8, 9, 10, and 11 can be covered. For computer science and software-oriented students, Chapters 1, 2, 3, 4, 5, and 10 can be covered in one semester. If instructors choose to introduce hardware before dealing with exceptions, they can switch the order of presentation of Chapters 5 and 6.

Each chapter is organized into four or five main sections, each dealing with an important topic. In most cases, each section has at least one example problem. The end-of-chapter problems are especially designed to supplement the material covered in the book. Most of these problems have been classroom tested. A comprehensive glossary is included at the end of the book.

The book is an outgrowth of several courses on microprocessors and digital systems taught by the author at Florida International University to engineering, technology, and computer science students. The author's association with the Motorola Corporation as a consulting professor, teaching their industrial seminars on the 68000 family of processors and applications, also significantly contributed to the book's development.

Nothing replaces a hands-on learning experience. Therefore, readers are encouraged to apply the software and hardware concepts introduced in this book to practical problems using the microcomputer system of their choice.

Acknowledgments

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The Microprocessor Evolution

It is no exaggeration to say that the microprocessor device has revolutionized digital electronics and the computer field. Most of the currently available digital, computer, and electronic systems use some form of microprocessor. With processing capability exceeding several million instructions per second (MIPS), the microprocessor is continuously finding new applications.

The earliest form of the microprocessor was a 4-bit device (4004). It was basically used as a 4-bit ALU (arithmetic logic unit) almost a quarter-century ago. The real microprocessor era started in the early 1970s, when Intel Corporation introduced the 8080 microprocessor. This was an 8-bit microprocessor, and contained an ALU and bus interface logic on board. It also had several 8-bit registers for storing operands and addresses. Although the unit required several power supplies and a power-sequencing scheme, it found extensive applications. The success of the 8080 microprocessor led other companies to get involved in the development of different forms of microprocessors.

Immediately after launching the 8080 processor, Intel began to improve its design, which resulted in the 8085. The 8085 processor is code compatible with the earlier 8080, but can operate on a single 5-volt power supply. Almost simultaneously, Motorola Corporation introduced the 8-bit 6800 microprocessor with nonmultiplexed data and address buses. The 6800 processor also incorporates the concept of double accumulators and has an index addressing scheme. The 6800 became an instant success. Several peripheral devices to interface with the 8085 and the 6800 processors were introduced into the market by a number of vendors.

During the mid-1970s, Commodore and Rockwell International introduced the 8-bit 6502 microprocessor, which also became an instant success. This machine is similar to the 6800 processor, but includes additional addressing capabilities such as memory indirect. The design of the Apple computer was based on the 6502 processor. At about the same time, Zilog Corporation introduced the 8-bit Z80 microprocessor. The Z80 is code compatible with the 8085 processor. It has additional resources with which to store data internally, and it also has the index addressing mode of the 6800 and 6502 processors. The Z80 processor found extensive applications in the 8-bit field, even though it entered the 8-bit market late.

Most of the processors we have mentioned were developed with NMOS technology. However ultralow power requirements dictated a processor using CMOS technology. RCA Corporation introduced the first CMOS 8-bit 1802 microprocessor for low-power applications. Pacemakers and several other battery-powered devices use the 1802 type of processor. Most 8-bit processors have a 64-kilobyte address range.

Emerging applications soon demanded more processing power than 8-bit processors could provide. Intel corporation was again the leader in introducing the first 16-bit 8086 microprocessor in 1978. The internal architecture of the 8086 supports 16-bit operations. The external address bus can access 1 megabyte of memory, which was considered a great advantage. The 8086 has a 16-bit data bus. The 8088 processor is a scaled-down version of the 8086, with an 8-bit data bus. The IBM PC contributed to the great success of the 8086/88 processors.

To follow the 8086 processor, Motorola Corporation introduced the much more powerful and versatile 68000 microprocessor. It has a 16-bit data bus and an effective 24-bit address bus that can access 16 megabytes. The internal architecture of the 68000 is designed to support 8-bit, 16-bit, and 32-bit operations. There are several 32-bit data registers, each of which can be used as an accumulator. The architecture, linear address range, and versatile data-handling capability of the 68000 suited the needs of industry. Systems such as Apple's Macintosh further contributed to the popularity of the 68000 processor. During the same time frame, Zilog corporation introduced its 16-bit Z8000 processor, which is similar to the 68000 in terms of architecture.

Continuous demand by industry resulted in the development of even more powerful processors, such as the 68020 and 68030 in the 68000 family, and the 80386 in the 8086 family. The present trend of development will continue in the 1990s. In order to obtain more dedicated throughput, RISC (reduced instruction set computer chip) devices are becoming popular. But the demand for general-purpose processors will continue to rise.

Also observed in the microprocessor application market is the popularity of single-chip microcomputers and controllers, such as Intel's 8051 and Motorola's 68HC11. These 8-bit devices are suitable for 8-bit I/O interface applications. Sixteen-bit microcontroller devices are also becoming available.

All of the 8-, 16-, and 32-bit processors we have described are available in various packages using different processing techniques.

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