

16/32-BIT MICROPROCESSORS 68000/68010/68020

*Software, Hardware, and Design
Applications*

WUNNAVA V. SUBBARAO

COMPUTER SCIENCE COMPUTER SCIENCE COMPUTER SCIENCE COMPU



MAXWELL
MACMILLAN
INTERNATIONAL
EDITIONS

COMPUTER SCIENCE COMPUTER SCIENCE COMPUTER SCIENCE COMPU

16/32-Bit Microprocessors: 68000/68010/68020

Software, Hardware, and Design Applications

WUNNAVA V. SUBBARAO

Florida International University

江苏工业学院图书馆
藏书章

**Merrill, an imprint of
Macmillan Publishing Company
New York**

**Collier Macmillan Canada, Inc.
Toronto**

**Maxwell Macmillan International Publishing Group
New York Oxford Singapore Sydney**

© Copyright 1991 by Macmillan Publishing Company.
Merrill is an imprint of Macmillan Publishing Company.

Printed in the Republic of Singapore

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Distribution rights in this edition are controlled exclusively by Maxwell Macmillan Publishing Singapore Pte. Ltd. and restricted to selected countries. This book may be sold only in the country to which it has been sold or consigned by Maxwell Macmillan Publishing Singapore Pte. Ltd. Re-export to any other country is unauthorized and a violation of the rights of the copyright proprietor.

Macmillan Publishing Company
866 Third Avenue, New York, New York 10022

Collier Macmillan Canada, Inc.

Library of Congress Catalog Card Number: 90-60538

ISBN 0-675-21119-0 (Hardcover Edition)
ISBN 0-02-946331-9 (International Edition)

IE Printing: 1 2 3 4 5 Year: 1 2 3 4 5

ISBN 0-02-946331-9

16/32-Bit Microprocessors: 68000/68010/68020

Software, Hardware, and Design Applications

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

*To the Department of Electrical and Computer Engineering, Florida International Uni-
versity, Miami, for providing me with an outstanding professional atmosphere in which
I could venture and complete this project*

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 pre-

sented. 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 codes, 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

Many people assisted me in the preparation of this book. Students in the Electrical Engineering and Computer Science departments at Florida International University were extremely helpful. In particular, I would like to thank Jorge Salinger, Laura Ruiz, Mauricio Salinas, Fernando Gonzalez, and Mike Urucinitz of the Electrical Engineering Department for their work in conducting hardware and software experiments to support the discussions in this book.

Motorola Corporation has been very generous in donating 68000- and 68020-based systems to the university. This allowed for the concepts presented in the text to be tested on real systems. Special thanks to Ben Ledonne and Fritz Wilson of the university support service at the Motorola Corporation in Phoenix for their support and encouragement.

I would like to acknowledge the encouragement and guidance offered by our chairperson, James Story, and the professional courtesy extended to me by our dean, Gordon Hopkins, and associate dean, Manuel Cereijo, during the preparation of the book. Many thanks also to Lie Lonie Boney and Lordis Barough for their assistance in preparing the materials for presentation. I am especially grateful to my wife, Sunanda.

and to my children, Madhavi and Manoj, for their immense patience and understanding during the course of the project.

Perhaps no words can express my gratitude to my teachers. They have given me a path objective, a career, and, above all, knowledge and self-esteem. Professor Earnest Anderson and Professor Edwin Anderson of North Dakota State University in Fargo and Professor D.L. Sastry, the late Professor S. Jnanananda, and Professor D.S. Sastry of Andhra University in Waltair and Masulipatam in India have been instrumental in shaping my present academic career. I remain ever grateful to them. I would also like to thank the reviewers of this edition for their important ideas and suggestions: Antony Alumkal, Austin Community College; Mike Bachelder, South Dakota School of Mines and Technology; Gary Boyington, Chemeketa Community College; George Frueh, Lincoln Technical Institute; Frank Gergelyi, Metropolitan Technical Institute; Jerry Noe, Tri Cities State Technical School; and John Skroder, Texas A&M University.

Acknowledgments

Many people assisted me in the preparation of this book. Students in the Electrical Engineering and Computer Science Department at Florida International University were extremely helpful in particular. I would like to thank Jorge Sainiger, Laura Ruiz, Maria Teresa, Fernando Gonzalez, and Mike Llanos of the Electrical Engineering Department for their work in conducting hardware and software experiments to support the discussions in this book.

Motorola Corporation has been very generous in donating 68000- and 68010-based systems to the university. This allowed for the concepts presented in the text to be tested on real systems. Special thanks to Ben Johnson and Betty Wilson of the university support services at the Motorola Corporation in Phoenix for their support and encouragement.

I would like to acknowledge the encouragement and guidance offered by our chairman, James Sney, and the professional courtesy extended to me by our dean, Gordon Hopkins, and associate dean, Manuel Cepeda, during the preparation of the book. Many thanks also to Eric John Boney and Linda Boney for their assistance in preparing the materials for presentation. I am especially grateful to my wife, Sunanda,

INTRODUCTION

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.

16/32–Bit Microprocessors: 68000/68010/68020

Software, Hardware, and Design Applications

CONTENTS

INTRODUCTION

CHAPTER 1

The 68000 Family of Microprocessors and Architecture

1.0	INTRODUCTION	2	
1.1	The 68000 FAMILY OF MICROPROCESSORS	2	
	The 68000 Microprocessor	2	
	The 68008 Microprocessor	2	
	The 68010 Microprocessor	3	
	The 68012 Microprocessor	3	
	The 68020 Microprocessor	4	
	The 68030 Microprocessor	4	
	The 68881 Coprocessor	4	
1.2	TYPICAL MICROCOMPUTER CONFIGURATION OF THE 68000 FAMILY	5	
	General Interface Scheme	5	
	Typical 68000-Based Systems	6	
1.3	GENERAL ARCHITECTURE OF THE 68000 MICROPROCESSOR	7	
	Data Registers D0–D7 (Dn)	7	
	Address Registers A0–A6 (An)	8	
	Stack Pointers A7 (USP) and A7' (SSP)	8	
	Program Counter (PC)	9	
	Status Register (SR) and Flag Structure	9	
	Other Resources	12	
	Supervisor and User Modes of Operation	13	

1.4 OTHER FEATURES OF THE 68000 FAMILY OF PROCESSORS 15

- Prefetch Queue 15
- The Instruction Pipeline 15

1.5 SUMMARY 15

- PROBLEMS 16
- ENDNOTES 18

CHAPTER 2

The 68000 Memory Organization Schemes, Data Structures, and Addressing Modes

19

2.0 INTRODUCTION 20

2.1 MEMORY ORGANIZATION SCHEMES AND DATA STRUCTURES 20

- Memory Organization and Selection Schemes 20
- Data Structures and Representation 21
- Stack and Queue Organization and Structure for the 68000 24

2.2 INSTRUCTION FORMAT AND STRUCTURE 26

- Instruction Format 27
- Instruction Structure 7

2.3 REGISTER DIRECT AND REGISTER INDIRECT

ADDRESSING MODES 28

- Register Direct Addressing Modes 30
- Register Indirect Addressing Modes 30

2.4 IMMEDIATE, QUICK, ABSOLUTE, RELATIVE, AND IMPLICIT ADDRESSING MODES 34

- Immediate Addressing Mode (Imm) 35
- Quick Addressing Mode (Q) 35
- Absolute Short and Long Addressing Modes (Abs.W, Abs.L) 36
- PC Relative with Displacement Addressing Mode d(PC) 37
- PC Relative with Index and Displacement Addressing Mode d(PC,Rn) 37
- Implicit Addressing Mode 38

2.5 SUMMARY 39

- PROBLEMS 41
- ENDNOTES 43

CHAPTER 3

The 68000 Instruction Set and Programming Considerations

44

3.0 INTRODUCTION 45

3.1 THE GENERAL INSTRUCTION SET 45

- Interpretation of the Instructions 45
- The Instruction Groups 50

3.2 DATA MOVEMENT AND ARITHMETIC INSTRUCTION GROUPS 52

- Data Movement Instructions 52
- Binary Integer Arithmetic Instructions 55
- BCD (Binary Coded Decimal) Instructions 62

3.3	LOGICAL AND BIT-MANIPULATION INSTRUCTION GROUPS	64
	Logic, Shift, and Rotate Instructions	65
	Bit-Manipulation Instructions	70
3.4	PROGRAM AND SYSTEM CONTROL INSTRUCTION GROUPS	73
	Program Control Instructions	73
	System Control Instructions	76
3.5	INSTRUCTION TIMING CONSIDERATIONS	78
	Read/Write Timing	78
	Instruction Timing Computation	78
3.6	SUMMARY	81
	PROBLEMS	82
	ENDNOTES	86

CHAPTER 4

68000 Software Considerations and Assembly Programming Applications

87

4.0	INTRODUCTION	88
4.1	ASSEMBLY LANGUAGE SOFTWARE AND PROGRAMMING TECHNIQUES	88
	Assembler, Cross Assembler, Linker, and Loader Utilities	88
	Writing Assembly Programs and Software Development	90
	Programming and Software Engineering Considerations	96
4.2	DATA MOVEMENT, DATA-COMPARISON SOFTWARE, AND APPLICATIONS	96
	Block Transfer Applications and Software Considerations	96
	Data-Sequencing Applications and Software Considerations	99
4.3	DATA PROCESSING APPLICATIONS AND SOFTWARE CONSIDERATIONS	101
	Multiprecision Addition and Subtraction Operations	102
	Multiplication and Division Operations	104
4.4	SPECIAL INSTRUCTION GROUPS AND APPLICATIONS	108
	Multiple-Decision Instructions	108
	Address, Stack, and Multiple-Movement Instructions	110
4.5	MACROS IN SOFTWARE DEVELOPMENT	115
4.6	SUMMARY	117
	PROBLEMS	118
	ENDNOTES	120

CHAPTER 5

68000 Exception Processing Considerations

121

5.0	INTRODUCTION	122
5.1	GENERAL CONCEPTS OF EXCEPTION PROCESSING	122
	The Exception Vector Table and Exception Vectors	122

Reset Exception Processing	123
General Scheme of Exception Processing	125
5.2 INTERRUPT EXCEPTIONS AND APPLICATIONS	128
Interrupt Mask Levels	128
Autovector and User Vector Methods	129
5.3 TRAP EXCEPTION PROCESSING AND APPLICATIONS	132
Using System Resources in the Supervisor Mode via Traps	133
Trap Software Routines and Applications	133
5.4 ERROR-RELATED EXCEPTIONS	135
Illegal Instruction, Unimplemented Instruction, and Privilege-Violation Conditions	136
Uninitialized and Spurious Interrupt Exceptions	137
Zero-divide, CHK, and Trace Exception Conditions	137
Address and Bus Error Conditions	138
Double Bus Fault Condition	142
5.5 SUMMARY	142
PROBLEMS	143
ENDNOTES	147
 CHAPTER 6	
68000 Hardware Considerations and Design Applications	148
6.0 INTRODUCTION	148
6.1 68000 HARDWARE SIGNALS AND FUNCTIONS	149
Address, Data, and Asynchronous Buses for the 68000	150
Function Code Outputs	151
Other Buses and Signals	152
6.2 MEMORY AND I/O INTERFACE SCHEMES	156
Memory-Device Types and Memory Concepts	156
Address Decoding, Strobing, and Memory Selection	157
Read and Write Timing Considerations	157
Timing Considerations of Asynchronous Inputs	160
6.3 MEMORY AND I/O SYSTEM DESIGN CONSIDERATIONS	162
The Memory Subsystem Design	162
Signal Buffering Considerations	164
6.4 CONTROL INTERFACE SCHEMES	166
Reset and Halt Interface	166
Timing Signals Associated with the 68000	168
Bus Error Considerations	169
6.5 68000-BASED BUSING SCHEMES	170
The VERSA Bus	170
The VME Bus	173

6.6 SUMMARY	176
PROBLEMS	176
ENDNOTES	179

CHAPTER 7

The 68000 Parallel Interface and Applications

180

7.0 INTRODUCTION	180
7.1 SYNCHRONOUS PARALLEL INTERFACE WITH THE 68000	181
6821 PIA (Peripheral Interface Adapter) Architecture	181
6821 PIA Synchronous Interface with the 68000	182
I/O Interface and Design Applications	183
7.2 THE 68230 PARALLEL INTERFACE AND TIMER (PI/T)	187
Registers and I/O Ports	187
Interfacing the 68230 PI/T	189
7.3 DATA ENTRY AND DISPLAY SYSTEMS	192
The Keyboard and Hex Display Interface	192
System Hardware and Software Considerations	192
Other Forms of Keyboard and Interface Schemes	197
7.4 ELECTROMECHANICAL APPLICATIONS	198
Rotational and Linear Stepper Motors	199
Stepper-Motor Interface Considerations	199
Position Control Systems	203
7.5 SUMMARY	204
PROBLEMS	205
ENDNOTES	208

CHAPTER 8

The 68000 Serial Interface and Applications

209

8.0 INTRODUCTION	209
8.1 SERIAL DATA COMMUNICATION CONCEPTS	210
8.2 6850 ACIA GENERAL ARCHITECTURE	212
Registers and I/O Ports	212
Modes of Operation and Status Conditions of the ACIA	213
8.3 THE 6850 ACIA INTERFACE WITH THE 68000 AND APPLICATIONS	216
68000/6850 Interface Considerations	216
RS-232 Interface Application	218
8.4 68901 MFP (MULTIFUNCTION PERIPHERAL) GENERAL ARCHITECTURE	220
Internal Architecture of the MFP	221
Register Structure and Modes of Operation	221