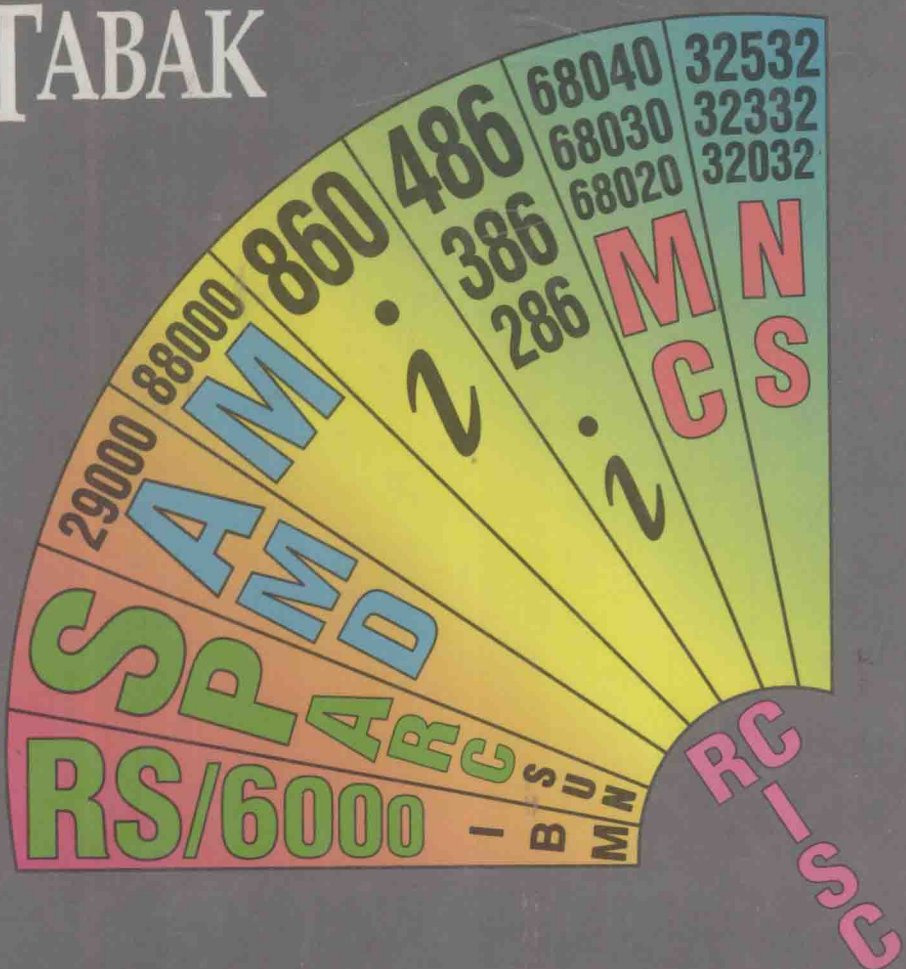
Advanced Microprocessors

Daniel Tabak



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To my wife PNINA, with love and appreciation

Preface

Since the appearance of microprocessors in the early 1970s, a vast number of books and manuals on this topic has been published. Most of the existing books are dedicated to specific microprocessor families, such as the Intel 80x86 or Motorola M68000. Moreover, most of the existing books dedicate the greater part of their text to the lower members of the above microprocessor families, such as the 8086 (80x86 family), or the MC68000 (M68000 family). Relatively little is said about the top-level members of the above families, such as the 80386, 80486 (80x86 family), or MC68030, MC68040 (M68000 family), and rarely in the same text. The new 80486 and MC68040 microprocessors have not been described at all, with the exception of being mentioned in a short paragraph here and there. The National Semiconductor microprocessors of the NS32000 family are not mentioned at all in the majority of existing texts. The new RISC-type microprocessors (Intel 80860, Motorola M88000, Sun SPARC, AMD 29000, and others) are described primarily in a small group of books dedicated to the RISC topic, but very rarely (and even then in insufficient detail) under the same cover with other microprocessors.

It is the purpose of this book to fill the gaps just described in the following manner:

By presenting the several microprocessor families of Intel 80x86, Motorola M68000, National Semiconductors NS32000, in considerable detail, under the same cover, along with some notable RISC-type microprocessors.

By stressing, and dedicating most of the space to, the top-level member of each family (as opposed to most existing texts).

By describing the top-level microprocessor, in detail, first and mentioning the other, lower members of the family (amply described in other books) subsequently.

The primary goal of this book is to serve as a concentrated reference of the top-level, advanced microprocessors of the most prominent (in the author's opinion) microprocessor families. An effort has been made to include as many details as possible within a limited space. This

book includes details on hardware, software, architecture, organization, and realization aspects of the included microprocessors.

The book can also serve as a text on advanced microprocessors at the senior and first year graduate level. A modest number of problems for students were added to the text. Solutions to the problems are available in an instructor's manual. The preprint of this book was successfully used by the author in the graduate course (also open to advanced seniors) ECE 516 Advanced Microprocessors, offered in the spring of 1990 at George Mason University, Department of Electrical and Computer Engineering (ECE).

The primary intended audience of this book are electrical and/or computer engineers and students majoring in the above disciplines. It can also be used by professionals and students of computer science or other engineering areas, if they have sufficient basic knowledge of computer hardware. This book is not intended for beginners. It is assumed that the reader has had a basic course on digital design (including both combinational and sequential logic circuitry) and on computer organization. It is also assumed that the reader has a basic knowledge of the simpler 8-bit microprocessors, such as the Intel 8085 or Zilog Z80.

Advanced Microprocessors is divided into six parts. Part 1 serves as a basic introduction, presenting a brief historical overview of the development of microprocessors in Chap. 1, a general discussion of the structure of advanced microprocessors in Chap. 2, and a basic introduction to microprocessor architecture in Chap. 3. The next three parts are dedicated to specific microprocessor families: Part 2—Intel 80x86, Part 3—Motorola M68000, and Part 4—National Semiconductor NS32000. Part 5 discusses a selected number of advanced RISC-type microprocessors, and Part 6 includes a general discussion of microprocessor-based system development and a comparison between different systems covered in Parts 2 to 5. A list of abbreviations is added at the end for the convenience of the reader.

Chapter 3 in Part 1 contains basic material dealing with assembly language programming. Readers familiar with this material may wish to skip it. It was the experience of this author that many engineering students and practicing engineers do not know this material well enough. For this reason this material was included.

The author was fortunate to receive valuable information and comments from prominent professionals who played a leading role in the creation of some of the advanced microprocessors described in this book. They are listed in the order of appearance of the appropriate system in the book: Pat Gelsinger (Intel 80486), Ralph C. McGarity (Motorola MC68040), Les Kohn (Intel 80860), and Dr. H. Brian Bakoglu (IBM RS/6000). Helpful information and comments were also

received from Tovey Barron and Chuck Swartley (Intel), Phil Brownfield (Motorola), Reuven Marko (National Semiconductor), and Max Baron (Sun Microsystems). The contributions of the above are highly appreciated.

Valuable comments, leading to considerable improvements in the text, were obtained from reviewers contacted by McGraw-Hill Publishing Company. The author is particularly indebted to James F. Fegen, Jr., of McGraw-Hill for continued support and encouragement in the preparation of the manuscript.

The manuscript was processed by the GMU Word Processing Unit, directed by Ms. Mary Blackwell. As in the author's previous books, the manuscript handling was timely and of high quality. The author would also like to express his appreciation to his wife Pnina for her understanding and patience.

Daniel Tabak

Advanced Microprocessors

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1

General Principles

Chapter

1

Introduction

In the mid-seventies it was easy to define a microprocessor. At that time one could say that a microprocessor is a central processing unit (CPU) realized on a large-scale integration (LSI) (50,000 or more transistors) chip, operating at a clock frequency of 1 to 5 MHz, constituting an 8-bit system (with very few initial 16-bit systems around), with two to seven general-purpose CPU 8-bit registers. Because of their relatively low cost and small size, the microprocessors permitted the use of digital computers in many areas where the use of the preceding mainframe and even minicomputers would not be practical and affordable. The advent of the microprocessor permitted placing a digital computer in practically every home.

The microprocessor has come a long way since the seventies [1.1–1.5]. The microprocessors of the late eighties and early nineties are full-scale 32-bit data and 32-bit address systems, operating at clock cycles of 25 to 50 MHz, realized on over 1 million transistors very large scale integration (VLSI) chips. They have 16 to 32 general-purpose CPU registers and some have a floating-point unit (FPU) and a considerable cache (8 to 12 kbytes) on chip. Their performance matches and sometimes exceeds the performance of superminicomputers (such as the VAX) and mainframe systems, and in some cases it becomes comparable to that of some supercomputers, such as the Cray. Under the circumstances, the distinction between microprocessors and other systems becomes more difficult.

The main point of distinction is the microprocessor's compact VLSI realization and its relatively low price for the attained high performance. This permits placing a digital computer endowed with supercomputer capabilities in cars, airplanes, boats, and eventually in every home.

The development of some major U.S.-based microprocessor families

is illustrated in Table 1.1. Intel started with the 4-bit 4004 in 1971, followed by the 8-bit 8008 in 1972. A more powerful 8-bit microprocessor, the 8080, was produced in 1974, followed by the top Intel 8-bit product, the 8085 [1.6]. Motorola started its 8-bit 6800 family, in parallel, in 1974, culminating with its top 8-bit product, the 6809, in 1977. Zilog came out with its 8-bit Z80 in 1975. The Z80 was developed by some former Intel professionals, who developed the 8080 and the 8085. The Z80 architecture is indeed very similar to that of the Intel 8080. The Z80 contains all of the 8080 instructions, and although the assembly language mnemonics are different, there is machine language compatibility [1.6]. The Z80 contains many more instructions than the 8080.

Table 1.1 is certainly not exhaustive. There were many more 8-bit microprocessors that made the scene in the seventies. Only the most prominent and the most widely used (in the author's opinion) are shown in the table. There were also a number of 16-bit microprocessors that appeared in the mid-seventies. None of them achieved the prominence and massive use of the Intel 86 family started in 1978 with the 16-bit 8086. Shortly afterward Motorola came out with its M68000 family, which also became one of the predominant microprocessor families, in parallel with Intel's 86.

TABLE 1.1 Major Microprocessor Families

	Year	Intel	Motorola	National Semiconductor	Zilog
4-bit	1971	4004			
8-bit	1972	8008			
	1973				
	1974	8080	6800		
	1975				Z80
	1976	8085			
	1977		6809		
16-bit	1978	8086			Z8000
	1979	8088	68000	16016	
	1980	80186	68008	16008	
	1981	80188	68010	16032	
	1982	80286			
	1983				
32-bit	1984		68020	32032	
	1985	80386			
	1986			32332	
	1987		68030		
	1988	80376		32532	
	1989	80486	68040		
	1990				
	?	80586			Z80000