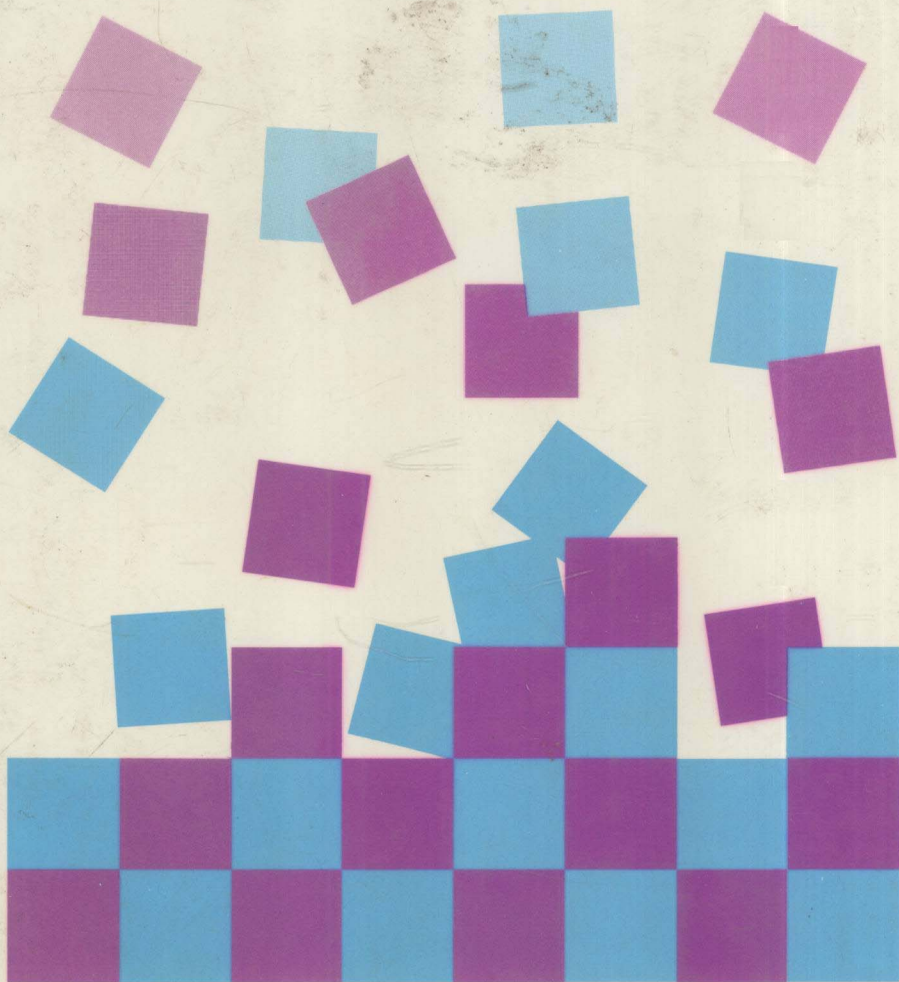


ADVANCED MICROPROCESSOR ARCHITECTURES

LUIGI CIMINIERA & ADRIANO VALENZANO



Electronic Systems Engineering Series

ADVANCED MICROPROCESSOR ARCHITECTURES

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**ADVANCED
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PREFACE

The advances achieved by microprocessors since their first appearance in the early 1970s are surprising, even in the rapidly evolving field of computers. The introduction of new features has caused technical innovations, in addition to changes in the technical background required to cope with them.

Early microprocessors were rather simple devices and the major problems encountered by users were concerned with developing programs in assembly language and interfacing to memory and I/O devices. In this framework, the typical microprocessor expert was usually an electronic engineer, with a hardware-oriented background, who was able to design rather small programs for modest application needs. From this point of view, the electronic engineer was regarded as a specialist in designing particular kinds of electronic circuits.

New 16- and 32-bit microprocessors include in their architectures features and supports that have been borrowed largely from mini-computer and mainframe technologies, and which rely heavily on the rapid progress achieved in the computer engineering and computer science fields. The main consequence of this is that microprocessor experts must now regard these devices as complex 'systems' rather than as special-purpose components. Hence, many of the basic concepts, such as those concerning operating systems, parallel processing and high-level language programming, must be included in the technical background of each modern microsystem designer.

Aims

The major goal of this book is to contribute to the technical knowledge needed by every modern microprocessor expert. It does this by addressing the main aspects underlying the design of modern microprocessor architectures. Since new commercial device families include

sophisticated support for operating system implementation, memory management, high-level language programming, floating-point computations and so on, this book presents the main concepts on which these mechanisms are based, and discusses them in the light of their impact on modern microprocessor architectures. In addition, some important examples of commercial microprocessors are presented to illustrate how these basic principles are reflected in the 'real' world.

In other words, this book introduces advanced microprocessors from a point of view that does not merely use the conventional description of their hardware characteristics, but tries to offer a comprehensive picture of the philosophy that led to the design of modern architectures.

Intended Audience and Prerequisite Knowledge

This book is suited to undergraduate students in Electronic Engineering and Computer Engineering wishing to learn the fundamentals of advanced microprocessor architectures. At the same time, the book is also oriented to postgraduate students and engineers needing to be abreast of technical progress in modern device families.

Microprocessor-based system designers and computer engineering professionals will find in this book up-to-date material on the main features and characteristics of advanced microprocessors, together with the most important examples of commercial architectures.

The reader should be familiar with simple (8-bit) microprocessors, possibly by having attended a first-level course on microprocessor architectures. In particular, he or she is expected to have a knowledge of the basic organization of computers, and to have gained some experience in assembly and high-level language programming techniques.

The book is oriented to an advanced course on microprocessors. Since the early chapters present several fundamental concepts concerning operating systems and high-level languages, the reader can derive greater benefit from attending former or parallel courses on operating system principles and compiler construction. In this way, he or she will be able to understand, on the one hand, how operating system and compiler principles are implemented in practice, while, on the other hand, fundamental concepts will be mastered in detail.

Organization

The book is organized into two groups of chapters. Chapters 1 to 4 introduce the most important architectural characteristics of advanced microprocessors from a general point of view, without particular

emphasis on any specific device. In contrast, Chapters 5 to 10 present the most popular and significant 'real' architectures, making use of the basic elements discussed in the early chapters.

- Chapter 1 summarizes the factors that led to modern design philosophy and deals with characteristics concerning data types, addressing modes and microprocessor instruction organization.
- Chapter 2 describes other important architectural features such as register organization, floating-point number representation and standardization, the role of the interrupt and trap mechanisms, and the function of some hardware and software debugging supports.
- Chapter 3 is devoted to multiprocessing and multitasking; thus, specific sections describe some basic concepts of operating systems such as process switching, mutual exclusion, process synchronization, process communication and process scheduling.
- Chapter 4 deals with memory management: memory hierarchy is discussed together with memory management mechanisms such as segmentation and paging. Further concepts, such as virtual memory and memory protection principles and supports, are also introduced.
- Chapters 5, 6, 7 and 8 present four popular 16- and 32-bit microprocessors: Zilog Z80000, Motorola MC68020, National Semiconductor NS32032 and Intel iAPX286.
- Chapter 9 describes the Intel iAPX432 system, perhaps the most important example of a 'capability-based' machine implemented on a few VLSI chips.
- The aim of the last chapter (Chapter 10) is to give the reader a taste of the emerging reduced instruction set (RISC) architecture approach, which has appeared in the last few years. For this purpose, some basic principles and examples concerning the RISC philosophy are presented.

Problems related to memory and I/O interfacing are not covered in this book, because advanced microprocessors do not show significant innovations in this field and, moreover, it is assumed that the reader has already been introduced to them by a previous course or by his or her own experience.

Each chapter is concluded by a set of questions and problems concerning the main topics introduced in the preceding sections. The main goal of these exercises is to supply the reader with an immediate and continuous means for checking his or her progress in understanding the concepts and principles presented throughout the book.

On the other hand, the set of problems presented in the appendix

is oriented to typical aspects of modern microprocessor-based system design. The aim of these exercises is to lead the reader to a critical evaluation of the possible alternative solutions that can be adopted for 'real' problems. At the same time, some small design examples are proposed to spur the reader's fancy and creativity.

Luigi Ciminiera
Adriano Valenzano
July 1987

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CHAPTER 1

MICROPROCESSOR ARCHITECTURE: DATA TYPES, ADDRESSING MODES AND INSTRUCTIONS

OBJECTIVES

The aims of this chapter are as follows:

- to look at the historical trends in the microprocessor evolution;
 - to explain the typical memory allocation and operations required to run programs written in high-level languages;
 - to explain how data types supported by advanced microprocessors can be used to implement data structures used in high-level languages;
 - to show how the addressing modes of advanced microprocessors work, and how they can be used to access data in those memory organizations needed to implement programs written in high-level languages;
 - to outline how some special instructions can be used to implement some typical operations required by high-level languages.
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| 1.1 The evolution of micro-computers: A brief history | 1.5 Data types |
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1.1 The evolution of microcomputers: A brief history

In a book devoted to the most recent advances in microprocessor architecture, it is not possible to avoid a brief description of the short, but intense, history of microcomputers. In a field that is evolving so rapidly, the technological scenario is also changing continuously; thus, to understand the current state of the art it is necessary to know the trends of the microprocessor evolution and their bearing on future developments. The first section of this book is devoted to a brief description of the major events in the microprocessor evolution, therefore following microprocessors' original introduction to the market.

Although companies such as General Electric, RCA and Viatron contributed to microprocessor developments prior to 1971, the Intel 4004, introduced at the end of 1971, is generally acknowledged as the first microprocessor commercially available. Not long after, in 1972, other microprocessors were announced and introduced, such as the Rockwell International 4-bit PPS-4, the Intel 8-bit 8008 and the National Semiconductor 16-bit IMP-16.

The motivations leading to the first microprocessor implementations were dictated by the increased demand for large control circuits, which could not be effectively implemented with the dedicated chips then available. Thus, the microprocessor was originally seen as a programmable electronic device that could replace hard-wired circuits used in the implementation of small peripheral controllers, such as printers, intelligent terminals and pocket calculators. The field of application and the technology available dictated the technical characteristics of such a device; for example, the 8008 had an 8-bit data path, 14-bit address (16 Kbytes address space), an instruction set providing capabilities to perform simple arithmetic (addition, subtraction) and logical operations on 8-bit integers, and a stack implemented in hardware within the CPU, with a limited size, which prevented the execution of software with a complex structure.

With further developments in integration technology it became possible for an ever increasing number of transistors to be implemented on the same silicon area, so that the microprocessor designer was faced with the problem of using the area freed by the technological advances.

From 1973 to 1977, only a few years after their first appearance, microprocessors were characterized by an 8-bit data path and a 16-bit address (64 Kbytes addressing space); the instruction set was enlarged to include some 16-bit data manipulations, since this feature enabled address computations, and the stack was implemented in main memory, allowing subroutine nesting to a large degree. The typical applications for these microprocessors (often referred to as 8-bit) were still found in the field of real-time control, as well as in industrial applications. Software was almost always written in assembly language because the relatively low