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出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，计算机学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅擘划了研究的范畴，还揭橥了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的计算机产业发展迅猛，对专业人才的需求日益迫切。这对计算机教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短、从业人员较少的现状下，美国等发达国家在其计算机科学发展的几十年间积淀的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀计算机教材将对我国计算机教育事业的发展起积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章图文信息有限公司较早意识到“出版要为教育服务”。自1998年始，华章公司就将工作重点放在了遴选、移译国外优秀教材上。经过几年的不懈努力，我们与Prentice Hall，Addison-Wesley，McGraw-Hill，Morgan Kaufmann等世界著名出版公司建立了良好的合作关系，从它们现有的数百种教材中甄选出Tanenbaum，Stroustrup，Kernighan，Jim Gray等大师名家的一批经典作品，以“计算机科学丛书”为总称出版，供读者学习、研究及庋藏。大理石纹理的封面，也正体现了这套丛书的品位和格调。

“计算机科学丛书”的出版工作得到了国内外学者的鼎力襄助，国内的专家不仅提供了中肯的选题指导，还不辞劳苦地担任了翻译和审校的工作；而原书的作者也相当关注其作品在中国的传播，有的还专诚为其书的中译本作序。迄今，“计算机科学丛书”已经出版了近百个品种，这些书籍在读者中树立了良好的口碑，并被许多高校采用为正式教材和参考书籍，为进一步推广与发展打下了坚实的基础。

随着学科建设的初步完善和教材改革的逐渐深化，教育界对国外计算机教材的需求和应用都步入一个新的阶段。为此，华章公司将加大引进教材的力度，在“华章教育”的总规划之下出版三个系列的计算机教材：针对本科生的核心课程，剔抉外版菁华而成“国外经典教材”系列；对影印版的教材，则单独开辟出“经典原版书库”；定位在高级教程和专业参考的“计算机科学丛书”还将保持原来的风格，继续出版新的品种。为了保证这三套丛书的权威性，同时也为了更好地为学校和老师们服务，华章公司聘请了中国科学院、北京大学、清华大学、国防科技大学、复旦大学、上海交通大学、南京大学、浙江大学、中国科技大学、哈尔滨工业大学、西安交通大学、中国人民大学、北京航空航天大学、北京邮电大学、中山大学、解放军理工大学、郑州大学、湖北工学院、中国国家信息安全测评认证中心等国内重点大学和科研机构在计算机的各个领域的著名学者组成“专家指导委员会”，为我们提供选题意见和出版监督。

“经典原版书库”是响应教育部提出的使用原版国外教材的号召，为国内高校的计算机教学度身订造的。在广泛地征求并听取丛书的“专家指导委员会”的意见后，我们最终选定了这30多种篇幅内容适度、讲解鞭辟入里的教材，其中的大部分已经被M.I.T.、Stanford、U.C. Berkley、C.M.U.等世界名牌大学采用。丛书不仅涵盖了程序设计、数据结构、操作系统、计算机体系结构、数据库、编译原理、软件工程、图形学、通信与网络、离散数学等国内大学计算机专业普遍开设的核心课程，而且各具特色——有的出自语言设计者之手、有的历三十年而不衰、有的已被全世界的几百所高校采用。在这些圆熟通博的名师大作的指引之下，读者必将在计算机科学的宫殿中由登堂而入室。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证，但我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。教材的出版只是我们的后续服务的起点。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方法如下：

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Carl Hamacher received his B.A.Sc. degree in engineering physics from the University of Waterloo, Canada, an M.Sc. degree in electrical engineering from Queen's University, Kingston, Canada, and a Ph.D. degree in electrical engineering from Syracuse University, New York. From 1968 to 1990 he was at the University of Toronto, where he was a Professor in the Departments of Electrical Engineering and Computer Science. He served as director of the Computer Systems Research Institute during 1984 to 1988, and as chairman of the Division of Engineering Science during 1988 to 1990. Since January 1991 he has been a Professor of Electrical and Computer Engineering at Queen's University. He served as the dean of the Faculty of Applied Science from 1991 to 1996. During 1978 to 1979, he was a visiting scientist at the IBM Research Laboratory in San Jose, California. In 1986, he was a research visitor at the Laboratory for Circuits and Systems associated with the University of Grenoble in France. In 1996 to 1997, he was a visiting professor in the Computer Science Department at the University of California at Riverside and in the LIP6 Laboratory of the University of Paris VI, France.

His research interests are in multiprocessors and multicomputers, focusing on their interconnection networks.

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His current research interests include computer architecture, field-programmable VLSI technology, and multiple-valued logic systems. He is a coauthor of three other books: *Fundamentals of Digital Logic with VHDL Design*, *Microcomputer Structures*, and *Field-Programmable Gate Arrays*. In 1990, he received the Wighton Fellowship for "innovative and distinctive contributions to undergraduate laboratory instruction."

Safwat Zaky received his B.Sc. degree in electrical engineering and B.Sc. in mathematics, both from Cairo University, Egypt, and his M.A.Sc. and Ph.D. degrees in electrical engineering from the University of Toronto. From 1969 to 1972 he was with Bell Northern Research, Bramalea, Ontario, where he worked on applications of electro-optics and magnetics in mass storage and telephone switching. In 1973, he joined the University of Toronto, where he is now a Professor in the Department of Electrical and Computer Engineering and the Department of Computer Science. Presently, he

serves as chair of the Department of Electrical and Computer Engineering. From 1980 to 1981, he was a senior visitor at the Computer Laboratory, University of Cambridge, England.

His research interests are in the areas of computer architecture, reliability of digital circuits, and electromagnetic compatibility. He is a coauthor of the book *Microcomputer Structures* and is a recipient of the IEEE Third Millennium Medal.

CONTENTS

PREFACE

This book is intended for use in a first-level course on computer organization in electrical engineering, computer engineering, and computer science curricula. The book is self-contained, assuming only that the reader has a basic knowledge of computer programming in a high-level language. Many students who study computer organization will have had an introductory course on digital logic circuits. Therefore, this subject is not covered in the main body of the book. However, we have provided an extensive appendix on logic circuits for those students who need it.

The book reflects our experience in teaching computer organization to three distinct groups of undergraduates: electrical and computer engineering undergraduates, computer science specialists, and engineering science undergraduates. We have always approached the teaching of courses in this area from a practical point of view. Thus, a key consideration in shaping the contents of the book has been to illustrate the principles of computer organization using examples drawn from commercially available computers. Our main examples are based on the following processors: ARM, Motorola 680X0, Intel Pentium, and Sun UltraSPARC.

It is important to recognize that digital system design is not a straightforward process of applying optimal design algorithms. Many design decisions are based largely on heuristic judgment and experience. They involve cost/performance and hardware/software tradeoffs over a range of alternatives. It is our goal to convey these notions to the reader.

We have endeavored to provide sufficient details to encourage the student to dig beyond the surface when dealing with ideas that seem to be intuitively obvious. We believe that this is best accomplished by giving real examples that are adequately documented. Block diagrams are a powerful means of describing organizational features of a computer. However, they can easily lead to an oversimplified view of the problems involved. Hence, they must be accompanied by the details of implementation alternatives.

The book is aimed at a one-semester course in engineering or computer science programs. It is suitable for both hardware- and software-oriented students. Even though the emphasis is on hardware, we have addressed a number of software issues, including basic aspects of compilers and operating systems related to instruction execution performance, coordination of parallel operations at the system level, and real-time applications. An understanding of hardware/software interaction and tradeoffs is necessary for computer specialists.

THE SCOPE OF THE BOOK

We now review the topics covered in sequence, chapter by chapter. The first eight chapters cover the basic principles of computer organization, operation, and performance.

The remaining four chapters deal with embedded systems, peripheral devices, processor family evolution patterns, and large computer systems.

Chapter 1 provides an overview of computer hardware and software and informally introduces terms that are dealt with in more depth in the remainder of the book. This chapter discusses the basic functional units and the ways they are interconnected to form a complete computer system. The role of system software is introduced and basic aspects of performance evaluation are discussed. A brief treatment of the history of computer development is also provided.

Chapter 2 gives a methodical treatment of machine instructions, addressing techniques, and instruction sequencing. Basic aspects of 2's-complement arithmetic are introduced to facilitate the discussion of the generation of effective addresses. Program examples at the machine instruction level, expressed in a generic assembly language, are used to discuss loops, subroutines, simple input-output programming, sorting, and linked list operations.

Chapter 3 illustrates implementation of the concepts introduced in Chapter 2 on three commercial processors — ARM, 68000, and Pentium. The ARM processor illustrates the RISC design style, the 68000 has an easy-to-teach CISC design, while the Pentium represents the most successful commercial design that combines the elements of both the CISC and RISC styles. The material is organized into three independent and complete parts. Each part includes all of the examples from Chapter 2 implemented in the context of the specific processor. It is sufficient to cover only one of the three parts to provide the continuity needed to follow the rest of the book. If laboratory experiments using one of the three processors are associated with the course, the relevant part of Chapter 3 can be covered in parallel with Chapter 2.

Input-output organization is developed in Chapter 4. The basics of I/O data transfer synchronization are presented, and a series of increasingly complex I/O structures are explained. Interrupts and direct-memory access methods are described in detail, including a discussion of the role of software interrupts in operating systems. Bus protocols and standards are also presented, with the PCI, SCSI, and USB standards being used as representative commercial examples.

Semiconductor memories, including SDRAM, Rambus, and Flash memory implementations, are discussed in Chapter 5. Caches and multiple-module memory systems are explained as ways for increasing main memory bandwidth. Caches are discussed in some detail, including performance modeling. Virtual-memory systems, memory management, and rapid address translation techniques are also presented. Magnetic and optical disks are discussed as components in the memory hierarchy.

Chapter 6 treats the arithmetic unit of a computer. Logic design for fixed-point add, subtract, multiply, and divide hardware, operating on 2's-complement numbers, is described. Lookahead adders and high-speed multipliers are explained, including descriptions of the Booth multiplier recoding and carry-save addition techniques. Floating-point number representation and operations, in the context of the IEEE Standard, are presented.

Chapter 7 begins with a register-transfer-level treatment of the implementation of instruction fetching and execution in a processor. This is followed by a discussion of processor implementation by both hardwired and microprogrammed control.