

普.通.高.等.学.校
计算机教育“十二五”规划教材

计算机科学导论

(英中双语版)

*AN INTRODUCTION TO COMPUTER
SCIENCE
(English-Chinese Bilingual)*

[英] 邓辉舫 (Deng Huifang)

邹才凤 (Zou Caifeng) ◆ 编著

[巴基斯坦] 娜西娅·安瓦 (Nazia Anwar)



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内 容 提 要

本书用英汉双语写成,系统而又概要地介绍了计算机学科的定义、范畴、特点以及发展与变化的规律等。本课程的目的不是让学生学习大量具体的专业知识,而是针对所有对计算机感兴趣的学生进行入门性导引。全书由16章组成,分为6大部分:绪论,数据表示与操作,计算机硬件,计算机软件,数据组织与抽象以及高级与前沿专题(例如,物联网、云计算、大数据等),涵盖了计算机科学各个领域(包括最新领域)的最新进展、所有经典与丰富的前沿主题,以及跨学科、跨行业的应用。可以拓展读者的知识视野,能够帮助他们较全面地了解计算机科学的学科特点与发展现状,为今后深入学习计算机科学的各门专业课程打下基础。本书每一章末尾都包含本章小结,附有参考读物及一定量的练习,以帮助学生巩固已学的知识和课后进行深入的探讨。

本书既适合国内高等院校各专业用作计算机基础课教材,也可以供希望了解计算机相关领域知识的非专业读者作为入门参考。

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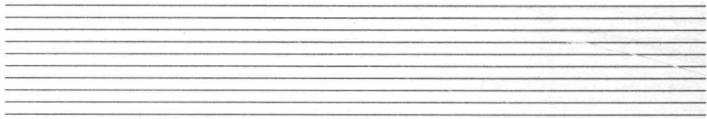
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Preface

Computer is constantly innovating all aspects of our lives. Computer science is a rapidly developing and expanding discipline. Computer networks link the world as a whole, and change the world we are living into a “global village”. The Internet of Things enables us to find anything at any time and anywhere. The cloud computing makes us to use the computing or storing resources as conveniently as we use water and electricity every day. The data science equips us with powerful intelligence to probe the unknown world. Breakthroughs in artificial intelligence exhibited by AlphaGo has surprised us. Novel material and drug syntheses, sophisticated defense system implementation, and the life’s code cracking heavily rely on supercomputers. Internet and e-commerce has changed our way of life. Even the evolution of the universe can be simulated by supercomputers. The human beings have gained huge profits by artificial intelligence, virtual reality, computer-aided design, medical diagnostics, computer animation, image & video processing, scientific computing, wearable computing, ubiquitous computing, multimedia, robotics, telecommunication and networking, internet of things, cloud computing, data science, and so on. Undoubtedly, computer has integrated into every aspect of our work and life. It has become the vital supporting tool for scientific research, business, finance, innovation of industry, national and social security, health care, public services, and so on. This book provides a concise introduction to computer science. It covers a wide range of subjects and topics, theoretical and applied, classic and state-of-the-art. It is not only suitable for students majoring in computer science, but also for those in all other majors who are interested in or wish to seek a broad and complete introduction.

Exclusive features

This book is easy for beginners to understand and helpful to stimulate students for further exploration. Several outstanding features of this book make itself unique.

This book contains a wide range of topics, varying in level of details, sophistication and difficulty. Its scope covers not only classic but also brand new hot areas, including but not limited to the topics from the classical data representation and operation, computer hardware and software, data organization and abstraction, network, algorithms, programming languages, software engineering, computational theory, to the cutting-edge hot topics, such as the fastest supercomputer, cloud computing, big data, Internet of Things, the latest video encoding and decoding methods, the popular programming languages collections, the latest operating systems, the vision of 5G wireless communications, the quantum cryptography in the network security, the latest

types of databases and management tools and the powerful computing platforms for big data, and the latest progress in the artificial intelligence etc.

This book uses many figures, tables and examples to demonstrate or interpret or visualize concepts. Throughout this book, we lay more emphasis on concepts or applications rather than theoretical models.

The style of the book is rich in visual and intuitive presentation. Many figures, tables, and examples are presented in the book to help readers grasp important and sophisticated concepts with ease.

Especially, for all key technical terms or phrases, idioms, and “hard nuts” appeared in this book, the corresponding Chinese translations are inserted just beside. This unique bilingual feature would help not only Chinese students, but also international students and technicians get a better understanding of the concepts in computer science or arouse their interest in taking this course.

Outline of the Course

After an introductory chapter, the book is divided into five parts.

Part I: Data representation and operation

This part includes Chapters 2, 3, and 4. Chapter 2 discusses number systems and their conversions; how a quantity can be represented using symbols or digital pattern and what are the mutual converting rules. Chapter 3 discusses data storage and data compression. Chapter 4 discusses some primitive operations on bits.

Part II: Computer hardware

This part consists of Chapters 5 and 6. Chapter 5 gives an overview of computer hardware, explaining different computer organizations. Chapter 6 discusses how individual computers are connected to make computer networks and internets and what kind of communication models and protocols are used. In particular, this chapter explores some areas related to the Internet and its applications.

Part III: Computer software

This part includes Chapters 7, 8, 9, and 10. Chapter 7 explores operating systems. Chapter 8 shows how to design an algorithm for problems. Chapter 9 takes a journey through the landscape of contemporary programming languages. Chapter 10 provides an overall review of software engineering.

Part IV: Data organization and abstraction

Part IV contains Chapters 11 and 12. Chapter 11 discusses data structures and abstract data types, and shows how different file structures can be used for different purposes. Chapter 12 discusses databases we come across every day.

Part V: Advanced topics

This part comprises Chapters 13, 14, 15, and 16. Chapter 13 deals with some issues related to network security. Chapter 14 discusses the theory of computation. Chapter 15 is an introduction to artificial intelligence, a topic with day-to-day challenges in computer science. Chapter 16 discusses Internet of Things, cloud computing, and data science.

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Unit 1

Introduction

This book provides a tour of computer science [计算机科学]. It presents the latest research about what computers do and how they do it, from top to bottom and outside to inside. A computer system is an accumulation of many different elements, combined to generate a whole that is far more than the sum of its parts. This book explores a wide range of topics. It aims to provide the foundational understanding of computer science, and establishes a comprehensive overview of this realm.

1.1 What Is Computer Science?

Computer science is a discipline that involves the theoretical foundations [理论基础] of computation and their applications in computer systems. It is difficult to list a complete range of computer research areas due to their rapid pace of innovation. This discipline contains many sub-fields, such as programming methodology and languages [程序设计方法学和语言], algorithm and data structure [算法和数据结构], computational complexity theory [计算复杂性理论], computer graphics [计算机图形学], operating systems [操作系统], software engineering [软件工程], database systems [数据库系统], artificial intelligence [人工智能], computer architecture [计算机系统结构], computer networking and communication [计算机网络与通信], parallel computation [并行计算], and so on.

Computer science is a relatively young discipline that begins in the 1940s. It spans theory and practice. It can be seen as a science of problem solving. It has strong associations with other disciplines. Many problems in engineering, science, medicine, agriculture, business, and other fields can be solved effectively with computers. The cross-disciplinary knowledge [交叉学科知识] is necessary in order to find a solution.

1.2 Von Neumann Model

The von Neumann model [冯·诺依曼模型] is a design architecture for an electronic digital computer [电子数字计算机]. It consists of an arithmetic logic unit [算术逻辑单元], a control unit [控制器], a memory [内存], an external storage [外部存储器], and input [输入] and output [输出] mechanisms (Figure 1.1).

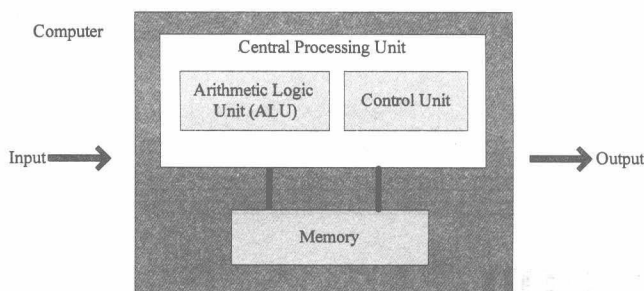


Figure 1.1 The von Neumann model

Computers based on the Turing machine【图灵机】store data【数据】in their memory. Around 1944-1945, John von Neumann proposed that programs【程序】should also be stored in the memory. Both data and programs in the von Neumann model have the same logical format. They are stored as binary【二进制】patterns in memory—a sequence of 0s and 1s. A program in the von Neumann model contains a finite number of instructions【指令】that are executed sequentially【按顺序执行】.

The bus【总线】is shared【共享】between the program memory and data memory, leading to the von Neumann bottleneck【瓶颈】. It has often been considered an issue due to the limited throughput【吞吐量】between the central processing unit (CPU)【中央处理单元(器)】and memory, because of the single bus that can only access one of the two classes of memory at a time. When the CPU is required to execute minimal processing on large amounts of data, it is forced to wait for needed data to be transferred to or from memory, which seriously limits the processing speed.

1.3 Computer Components

A computing system consists of hardware【硬件】, software【软件】, and data【数据】. Computer hardware is the collection of physical parts of a computer, such as a monitor【显示器】, a graphic card【显卡】, a hard disk drive (HDD)【硬盘驱动器】, a sound card【声卡】, memory, a motherboard【主板】, a mouse【鼠标】, a keyboard【键盘】, and so on. Computer software is a collection of computer programs, procedures, and documentation. Data is the distinct information with which a computer system deals.

1.3.1 Computer hardware

Computer hardware refers to the components that you can physically touch. There are many parts of computer hardware that can be installed inside, or connected to the outside, of a computer. The external hardware includes a flat-panel【平板显示器】, a printer【打印机】, a projector【投影仪】, a scanner【扫描仪】, a speaker【扬声器】, a keyboard, a mouse, a flash memory【闪存】, and so on. The internal hardware includes CPU, a multi-core processor【多核处理器】, a motherboard, a network card【网卡】, a modem【调制解调器】, a sound card, a video card【显卡】, a drive (e.g. Blue-Ray【蓝光】, CD-ROM【只读光盘驱动器】, DVD【数字通用光盘】, floppy drive【软盘驱动器】, hard disk drive (HDD)【硬盘驱动器】), a solid-state disk (SSD)【固态硬盘】, and so on.

1.3.2 Computer software

Computer software is any set of programs that a computer carries out【执行】. The program consists of a sequence of instructions. Each instruction operates on one or more data items. These instructions might be internal system commands【系统命令】, or responses to external input. Software informs the various hardware components what to do and how to interact with each other.

There are two main types of software: system software【系统软件】 and application software【应用软件】. System software is used to run the hardware, while application software is used to perform other tasks. The main system software includes operating systems【操作系统】 and drivers【驱动程序】. The main application software includes games, media players, word processors, anti-virus programs【杀毒软件】, and so on. Software is usually written in high-level programming languages【高级编程语言】, which are translated into the machine language【机器语言】 by a compiler【编译器】 or an interpreter【解释器】. Software may also be written in a low-level assembly language【汇编语言】.

1.3.3 Data

Data is any sequence of symbols given meaning by specific actions of interpretation【解释】. In daily life, we usually use digits that can take one of ten states (0 to 9). However, data stored in a computer generally use only two states (0 and 1). Some forms of data (text, image, audio, and video) cannot be stored in a computer directly, and needs to be converted into the binary【二进制】 form (0s and 1s).

Data can be organized in many types of data structures【数据结构】, including arrays【数组】, lists【列表】, graphs【图】, and objects【对象】. Modern high performance data persistence【数据持久性】 technologies rely on massively parallel distributed data processing【并行分布式数据处理】, such as Apache Hadoop. In such systems, the data is distributed across multiple computers and can be processed on different computers at the same time.

1.4 History and Development Trends

Computer science has undergone a rapid development since its birth. As the field of computer science has emerged, new directions of research and applications have been created and combined with classical discoveries in a continuous cycle of growth and revitalization.

1.4.1 Computer history

Life without a computer is unimaginable. The history of computer is an attractive story. Computers were not always the brilliant fast machines empowering us to obtain lots of knowledge. Actually, the first computer was very different from the recent computers. Generally speaking, history of computers can be divided into three periods.

1. Mechanical machines

In the early 17th century, a French mathematician called Blaise Pascal invented Pascaline, which is

a mechanical calculator【机械计算器】 performing addition【加法】 and subtraction【减法】. In the late 17th century, Gottfried Leibnitz, a German mathematician, invented Leibnitz' Wheel. In the early 19th century, Joseph-Marie Jacquard invented Jacquard loom, which adopted the idea of storage and programming at the first time. In the 1820s, Charles Babbage invented Analytical Engine. In 1890, Herman Hollerith invented a programmable machine that could read and sort data on punched cards automatically.

2. Electronic computers

Between 1930 and 1950, several scientists contributed to the evolution of computer technology who could be considered the true early pioneers of computer science. John Vincent Atanasoff and his assistant Clifford Berry invented the ABC (Atanasoff Berry Computer) to solve a system of linear equations. It encoded information electrically. In the 1930s, a huge computer called Mark I, was built under the direction of Howard Aiken at Harvard University. In England, Alan Turing invented a computer called Colossus to break the German Enigma code. In 1946, John Mauchly and J. Presper Eckert invented ENIAC (Electronic Numerical Integrator and Calculator), the first totally electronic computer【电子计算机】. In 1950, EDVAC, the first computer to implement the stored program concept based on von Neumann's ideas was built at the University of Pennsylvania.

3. Computers after 1950

Between 1950 and 1959, computers were bulky and utilized vacuum tubes【电子管】 as electronic switches. Between 1959 and 1965, transistors【晶体管】 replaced vacuum tubes. Then the size and the cost of the transistorized computers were dramatically reduced. From 1965 to 1975, the appearance of the integrated circuit【集成电路】 further reduced the size and cost of computers. Between 1975 and 1985, microcomputers appeared. The Altair 8800, the first desktop calculator【台式计算机】, was invented in 1975. Between 1985 and 1995, some advanced computer technology appeared, such as Clusters【集群】, Vector Processors【向量处理器】, workstations【工作站】, minicomputers【小型计算机】, laptops【笔记本电脑】 and palmtop computers【掌上电脑】, and so on. After 1995, high-performance computers (HPC)【高性能计算机】 obtained a great advancement, such as supercomputers【超级计算机】, many-cores【多核】 personal computers【个人电脑】, graphics processing unit (GPU)【图形处理单元(器)], general-purpose graphics processing unit (GPGPU)【通用计算图形处理单元(器)], and so on.

1.4.2 Development trends

In the future, computer technology will be characterized by high performance, miniaturization, network, popularization, intelligence, and humanization.

1. Lightweight microcomputer

The lightweight microcomputer【微型计算机】 with small size, low price, powerful function, and high reliability will be popular.

- A Pocket PC【掌上电脑】 is a handheld device【手持设备】 that can be used to process e-mail, play games, exchange messages, browse the Web, and so on.
- A laptop computer【笔记本电脑】 has most of the same components into a single unit as a

desktop computer, such as a keyboard, a pointing device, a display, and speakers. Laptop computers have become increasingly popular because they are becoming smaller, lighter, cheaper, and more powerful, and their screens are becoming smaller and of better quality.

- A smart phone 【智能手机】 is based on a mobile operating system. The early smart phones added the functions of a personal digital assistant (PDA) 【个人数字助理】, a portable media player, a low-end compact digital camera, and a pocket video camera. Many modern smart phones also contain high-resolution touch screens 【触摸屏】, web browsers, global positioning system (GPS) 【全球定位系统】 navigation 【导航】 units, and so on.
- An iPad is a kind of tablet computers 【平板电脑】 built on Apple's iOS operating system. An iPad includes the functions of video players, cameras, music players, web browsers, emails, games, GPS navigations, social services, etc.

2. High performance computer

Development of powerful super computers with high speed, high performance, and capability of processing large and complex problems is also the definite trend.

- A parallel computer 【并行计算机】 has a set of processors that work simultaneously 【同时运行】. Parallel computers use multiple computational resources to solve large problems that can often be divided into smaller ones. From smart phones, to large supercomputers and web sites, to multi-core CPUs and GPUs, parallel processing is ubiquitous in modern computing.
- A graphics processing unit (GPU) 【图形处理单元(器)】 is a specialized electronic circuit used to rapidly handle memory to accelerate the processing of images. GPU computing utilizes a GPU together with a CPU to accelerate business, scientific and engineering applications. GPU + CPU is a powerful union because GPUs consist of thousands of small, efficient cores designed for parallel computing, and CPUs consist of a few cores optimized for serial computing 【串行计算】. The compute unified device architecture (CUDA) 【统一计算设备架构】 is a parallel computing platform and an application programming interface (API) 【应用程序编程接口】 model invented by NVIDIA. The CUDA-enabled GPU can be used for general purpose computing. The CUDA parallel computing platform provides a few simple C and C++ extensions to express data and task parallelism.
- A supercomputer 【超级计算机】 has high-level processing capacity that makes it possible to calculate problems at ultra-high speed. Supercomputers can be used for highly calculation-intensive tasks such as quantum physics 【量子物理】, weather forecasting, climate research, oil and gas exploration, etc.

1.5 Frontiers of Computer Technology

The frontiers of computer technology include supercomputers, cloud computing【云计算】, big data 【大数据】, Internet of Things 【物联网】, mobile computing 【移动计算】, quantum computers 【量子计算机】, biocomputers 【生物计算机】, virtualization 【虚拟化】, service-oriented architecture (SOA) 【面向服务的体系结构】, etc.

1.5.1 Supercomputer

A supercomputer is a computer that performs calculation at the currently highest operational rate. It is typically used for scientific and engineering applications that deal with very large databases or do large amounts of computation (or both). Figure 1.2 shows that supercomputing has increasingly become the cornerstone of modern society.

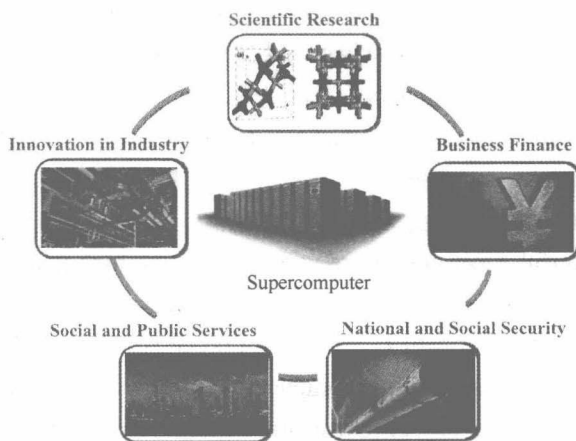


Figure 1.2 Supercomputing has increasingly become the cornerstone of modern society

Supercomputers play an important role in the field of computational science. The stages of supercomputer application include simulation【仿真】 and modeling【建模】, weather forecasting, meteorology【气象学】, geological exploration【地质勘探】, cryptography【密码学】 (encryption【加密】 and decryption【解密】), virtual reality【虚拟现实】, artificial intelligence【人工智能】, nuclear weapons【核武器】 development, precise guide missile【引导导弹】, long-range attack【远程攻击】, quantum simulation【量子模拟】, novel drug synthesis and discovery【新型药物的合成和发现】, novel material synthesis【新材料的合成】, space explorations【太空探索】, data mining【数据挖掘】, business intelligence, etc. Supercomputers can be applied to calculate the structures and properties of chemical compounds【化合物】, biological macromolecules【生物大分子】, polymers【聚合物】, and crystals【晶体】. High performance supercomputers are widely employed in physical simulations, such as simulation of airplanes in wind tunnels【风洞】, simulation of the detonation【爆炸】 of nuclear weapons, and research into nuclear fusion【核聚变】.

According to the 47th edition of the TOP 500 list of the world's most powerful supercomputers announced in June 2016, China maintained its No. 1 ranking, but with a new system built entirely using processors designed and made in China. Sunway TaihuLight【神威·太湖之光】 is the new No. 1 system with 93 petaflop/s (quadrillions of calculations per second【每秒 1000 万亿次运算】) on the LINPACK benchmark.

Developed by the National Research Center of Parallel Computer Engineering & Technology (NRCP CET) and installed at the National Supercomputing Center in Wuxi, Sunway TaihuLight displaces Tianhe-2 (Milkyway-2)【天河二号】, an Intel-based Chinese supercomputer that has retained the No. 1 position on the past six TOP 500 lists. Table 1.1 shows the top 10 sites for June 2016.