教育部高等教育司推荐
国外优秀信息科学与技术系列教学用书

数据库系统概念

（第六版 影印版）

DATABASE SYSTEM CONCEPTS

(Sixth Edition)

Abraham Silberschatz
Henry F. Korth
S. Sudarshan

高等教育出版社

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序

20世纪末，以计算机和通信技术为代表的信息科学和技术对世界经济、科技、军事、教育和文化等产生了深刻影响。信息科学技术的迅速普及和应用，带动了世界范围信息产业的蓬勃发展，为许多国家带来了丰厚的回报。

进入21世纪，尤其随着我国加入WTO，信息产业的国际竞争将更加激烈。我国信息产业虽然在20世纪末取得了迅猛发展，但与发达国家相比，甚至与印度、爱尔兰等国家相比，还有很大差距。国家信息化的发展速度和信息产业的国际竞争能力，最终都将取决于信息科学技术人才的质量和数量。引进国外信息科学和技术优秀教材，在有条件的学校推动开展英语授课或双语教学，是教育部为加快培养大批高质量的信息技术人才采取的一项重要举措。

为此，教育部要求由高等教育出版社首先开展信息科学和技术教材的引进试点工作。同时提出了两点要求，一是要高水平，二是要低价格。在高等教育出版社和信息科学技术引进教材专家组的努力下，经过比较短的时间，第一批引进的20多种教材已经陆续出版。这套教材出版后受到了广泛的好评，其中有不少是世界信息科学技术领域著名专家、教授的经典之作和反映信息科学技术最新进展的优秀作品，代表了目前世界信息科学技术教育的一流水平，而且价格也是最优惠的，与国内同类自编教材相当。

这项教材引进工作是在教育部高等教育司和高教社的共同组织下，由国内信息科学技术领域的专家、教授广泛参与，在对大量国外教材进行多次遴选的基础上，参考了国内和国外著名大学相关专业的课程设置进行系统引进的。其中，John Wiley公司出版的贝尔实验室信息科学研究中心副总裁Silberschatz教授的经典著作《操作系统概念》，是我们经过反复谈判，做了很多努力才得以引进的。William Stallings先生曾编写了在美国深受欢迎的信息科学技术系列教材，其中有多种教材获得过美国教材和学术著作者协会颁发的计算机科学与工程教材奖，这批引进教材中就有他的两本著作。留美中国学者Jiawei Han先生的《数据挖掘》是该领域中具有里程碑意义的著作。由达特茅斯学院Thomas Cormen和麻省理工学院、哥伦比亚大学的几位学者共同编著的经典著作《算法导论》，在经历了11年的锤炼之后于2001年出版了第二版。目前任教于美国Massachusetts大学的James Kurose教授，曾在美国三所高校先后10次获得杰出教师或杰出教学奖，由他主编的《计算机网络》出版后，以其体系新颖、内容先进而备受欢迎。在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作。这套引进的教材体现了权威性、系统性、先进性和经济性等特点。

教育部也希望国内和国外的出版商积极参与此项工作，共同促进中国信息技术教育和信息产业的发展。我们在与外商的谈判工作中，不仅要坚定不移地引进国外最优秀的教材，而且还要千方百计地将版权转让费降下来，要让引进教材的

价格与国内自编教材相当，让广大教师和学生负担得起。中国的教育市场巨大，外国出版公司和国内出版社要通过扩大发行数量取得效益。

在引进教材的同时，我们还应做好消化吸收，注意学习国外先进的教学思想和教学方法，提高自编教材的水平，使我们的教学和教材在内容体系上，在理论与实践的结合上，在培养学生的动手能力上能有较大的突破和创新。

目前，教育部正在全国35所高校推动示范性软件学院的建设和实施，这也是加快培养信息科学技术人才的重要举措之一。示范性软件学院要立足于培养具有国际竞争力的实用性软件人才，与国外知名高校或著名企业合作办学，以国内外著名IT企业为实践教学基地，聘请国内外知名教授和软件专家授课，还要率先使用引进教材开展教学。

我们希望通过这些举措，能在较短的时间，为我国培养一大批高质量的信息技术人才，提高我国软件人才的国际竞争力，促进我国信息产业的快速发展，加快推动国家信息化进程，进而带动整个国民经济的跨越式发展。

教育部高等教育司

In memory of my father Joseph Silberschatz
my mother Vera Silberschatz
and my grandparents Stepha and Aaron Rosenblum

Avi Silberschatz

To my wife, Joan
my children, Abigail and Joseph
and my parents, Henry and Frances

Hank Korth

To my wife, Sita
my children, Madhur and Advaith
and my mother, Indira

S. Sudarshan

Preface

Database management has evolved from a specialized computer application to a central component of a modern computing environment, and, as a result, knowledge about database systems has become an essential part of an education in computer science. In this text, we present the fundamental concepts of database management. These concepts include aspects of database design, database languages, and database-system implementation.

This text is intended for a first course in databases at the junior or senior undergraduate, or first-year graduate, level. In addition to basic material for a first course, the text contains advanced material that can be used for course supplements, or as introductory material for an advanced course.

We assume only a familiarity with basic data structures, computer organization, and a high-level programming language such as Java, C, or Pascal. We present concepts as intuitive descriptions, many of which are based on our running example of a university. Important theoretical results are covered, but formal proofs are omitted. In place of proofs, figures and examples are used to suggest why a result is true. Formal descriptions and proofs of theoretical results may be found in research papers and advanced texts that are referenced in the bibliographical notes.

The fundamental concepts and algorithms covered in the book are often based on those used in existing commercial or experimental database systems. Our aim is to present these concepts and algorithms in a general setting that is not tied to one particular database system. Details of particular database systems are discussed in Part 9, "Case Studies."

In this, the sixth edition of *Database System Concepts*, we have retained the overall style of the prior editions while evolving the content and organization to reflect the changes that are occurring in the way databases are designed, managed, and used. We have also taken into account trends in the teaching of database concepts and made adaptations to facilitate these trends where appropriate.

Organization

The text is organized in nine major parts, plus five appendices.

- **Overview** (Chapter 1). Chapter 1 provides a general overview of the nature and purpose of database systems. We explain how the concept of a database system has developed, what the common features of database systems are, what a database system does for the user, and how a database system interfaces with operating systems. We also introduce an example database application: a university organization consisting of multiple departments, instructors, students, and courses. This application is used as a running example throughout the book. This chapter is motivational, historical, and explanatory in nature.
- **Part 1: Relational Databases** (Chapters 2 through 6). Chapter 2 introduces the relational model of data, covering basic concepts such as the structure of relational databases, database schemas, keys, schema diagrams, relational query languages, and relational operations. Chapters 3, 4, and 5 focus on the most influential of the user-oriented relational languages: SQL. Chapter 6 covers the formal relational query languages: relational algebra, tuple relational calculus, and domain relational calculus.

  The chapters in this part describe data manipulation: queries, updates, insertions, and deletions, assuming a schema design has been provided. Schema design issues are deferred to Part 2.
- **Part 2: Database Design** (Chapters 7 through 9). Chapter 7 provides an overview of the database-design process, with major emphasis on database design using the entity-relationship data model. The entity-relationship data model provides a high-level view of the issues in database design, and of the problems that we encounter in capturing the semantics of realistic applications within the constraints of a data model. UML class-diagram notation is also covered in this chapter.

  Chapter 8 introduces the theory of relational database design. The theory of functional dependencies and normalization is covered, with emphasis on the motivation and intuitive understanding of each normal form. This chapter begins with an overview of relational design and relies on an intuitive understanding of logical implication of functional dependencies. This allows the concept of normalization to be introduced prior to full coverage of functional-dependency theory, which is presented later in the chapter. Instructors may choose to use only this initial coverage in Sections 8.1 through 8.3 without loss of continuity. Instructors covering the entire chapter will benefit from students having a good understanding of normalization concepts to motivate some of the challenging concepts of functional-dependency theory.

  Chapter 9 covers application design and development. This chapter emphasizes the construction of database applications with Web-based interfaces. In addition, the chapter covers application security.

- **Part 3: Data Storage and Querying** (Chapters 10 through 13). Chapter 10 deals with storage devices, files, and data-storage structures. A variety of data-access techniques are presented in Chapter 11, including B^+-tree indices and hashing. Chapters 12 and 13 address query-evaluation algorithms and query optimization. These chapters provide an understanding of the internals of the storage and retrieval components of a database.

- **Part 4: Transaction Management** (Chapters 14 through 16). Chapter 14 focuses on the fundamentals of a transaction-processing system: atomicity, consistency, isolation, and durability. It provides an overview of the methods used to ensure these properties, including locking and snapshot isolation.

  Chapter 15 focuses on concurrency control and presents several techniques for ensuring serializability, including locking, timestamping, and optimistic (validation) techniques. The chapter also covers deadlock issues. Alternatives to serializability are covered, most notably the widely-used snapshot isolation, which is discussed in detail.

  Chapter 16 covers the primary techniques for ensuring correct transaction execution despite system crashes and storage failures. These techniques include logs, checkpoints, and database dumps. The widely-used ARIES algorithm is presented.

- **Part 5: System Architecture** (Chapters 17 through 19). Chapter 17 covers computer-system architecture, and describes the influence of the underlying computer system on the database system. We discuss centralized systems, client–server systems, and parallel and distributed architectures in this chapter.

  Chapter 18, on parallel databases, explores a variety of parallelization techniques, including I/O parallelism, interquery and intraquery parallelism, and interoperation and intraoperation parallelism. The chapter also describes parallel-system design.

  Chapter 19 covers distributed database systems, revisiting the issues of database design, transaction management, and query evaluation and optimization, in the context of distributed databases. The chapter also covers issues of system availability during failures, heterogeneous distributed databases, cloud-based databases, and distributed directory systems.

- **Part 6: Data Warehousing, Data Mining, and Information Retrieval** (Chapters 20 and 21). Chapter 20 introduces the concepts of data warehousing and data mining. Chapter 21 describes information-retrieval techniques for querying textual data, including hyperlink-based techniques used in Web search engines.

  Part 6 uses the modeling and language concepts from Parts 1 and 2, but does not depend on Parts 3, 4, or 5. It can therefore be incorporated easily into a course that focuses on SQL and on database design.

- **Part 7: Specialty Databases** (Chapters 22 and 23). Chapter 22 covers object-based databases. The chapter describes the object-relational data model, which extends the relational data model to support complex data types, type inheritance, and object identity. The chapter also describes database access from object-oriented programming languages.

  Chapter 23 covers the XML standard for data representation, which is seeing increasing use in the exchange and storage of complex data. The chapter also describes query languages for XML.

- **Part 8: Advanced Topics** (Chapters 24 through 26). Chapter 24 covers advanced issues in application development, including performance tuning, performance benchmarks, database-application testing, and standardization.

  Chapter 25 covers spatial and geographic data, temporal data, multimedia data, and issues in the management of mobile and personal databases.

  Finally, Chapter 26 deals with advanced transaction processing. Topics covered in the chapter include transaction-processing monitors, transactional workflows, electronic commerce, high-performance transaction systems, real-time transaction systems, and long-duration transactions.

- **Part 9: Case Studies** (Chapters 27 through 30). In this part, we present case studies of four of the leading database systems, PostgreSQL, Oracle, IBM DB2, and Microsoft SQL Server. These chapters outline unique features of each of these systems, and describe their internal structure. They provide a wealth of interesting information about the respective products, and help you see how the various implementation techniques described in earlier parts are used in real systems. They also cover several interesting practical aspects in the design of real systems.

- **Appendices**. We provide five appendices that cover material that is of historical nature or is advanced; these appendices are available only online on the Web site of the book (http://www.db-book.com). An exception is Appendix A, which presents details of our university schema including the full schema, DDL, and all the tables. This appendix appears in the actual text.

  Appendix B describes other relational query languages, including QBE Microsoft Access, and Datalog.

  Appendix C describes advanced relational database design, including the theory of multivalued dependencies, join dependencies, and the project-join and domain-key normal forms. This appendix is for the benefit of individuals who wish to study the theory of relational database design in more detail, and instructors who wish to do so in their courses. This appendix, too, is available only online, on the Web site of the book.

  Although most new database applications use either the relational model or the object-relational model, the network and hierarchical data models are still in use in some legacy applications. For the benefit of readers who wish to learn about these data models, we provide appendices describing the network and hierarchical data models, in Appendices D and E respectively.

The Sixth Edition

The production of this sixth edition has been guided by the many comments and suggestions we received concerning the earlier editions, by our own observations while teaching at Yale University, Lehigh University, and IIT Bombay, and by our analysis of the directions in which database technology is evolving.

We have replaced the earlier running example of bank enterprise with a university example. This example has an immediate intuitive connection to students that assists not only in remembering the example, but, more importantly, in gaining deeper insight into the various design decisions that need to be made.

We have reorganized the book so as to collect all of our SQL coverage together and place it early in the book. Chapters 3, 4, and 5 present complete SQL coverage. Chapter 3 presents the basics of the language, with more advanced features in Chapter 4. In Chapter 5, we present JDBC along with other means of accessing SQL from a general-purpose programming language. We present triggers and recursion, and then conclude with coverage of online analytic processing (OLAP). Introductory courses may choose to cover only certain sections of Chapter 5 or defer sections until after the coverage of database design without loss of continuity.

Beyond these two major changes, we revised the material in each chapter, bringing the older material up-to-date, adding discussions on recent developments in database technology, and improving descriptions of topics that students found difficult to understand. We have also added new exercises and updated references. The list of specific changes includes the following:

- **Earlier coverage of SQL.** Many instructors use SQL as a key component of term projects (see our Web site, www.db-book.com, for sample projects). In order to give students ample time for the projects, particularly for universities and colleges on the quarter system, it is essential to teach SQL as early as possible. With this in mind, we have undertaken several changes in organization:
  - A new chapter on the relational model (Chapter 2) precedes SQL, laying the conceptual foundation, without getting lost in details of relational algebra.
  - Chapters 3, 4, and 5 provide detailed coverage of SQL. These chapters also discuss variants supported by different database systems, to minimize problems that students face when they execute queries on actual database systems. These chapters cover all aspects of SQL, including queries, data definition, constraint specification, OLAP, and the use of SQL from within a variety of languages, including Java/JDBC.
  - Formal languages (Chapter 6) have been postponed to after SQL, and can be omitted without affecting the sequencing of other chapters. Only our discussion of query optimization in Chapter 13 depends on the relational algebra coverage of Chapter 6.

- **New database schema.** We adopted a new schema, which is based on university data, as a running example throughout the book. This schema is more intuitive and motivating for students than the earlier bank schema, and illustrates more complex design trade-offs in the database-design chapters.
- **More support for a hands-on student experience.** To facilitate following our running example, we list the database schema and the sample relation instances for our university database together in Appendix A as well as where they are used in the various regular chapters. In addition, we provide, on our Web site http://www.db-book.com, SQL data-definition statements for the entire example, along with SQL statements to create our example relation instances. This encourages students to run example queries directly on a database system and to experiment with modifying those queries.
- **Revised coverage of E-R model.** The E-R diagram notation in Chapter 7 has been modified to make it more compatible with UML. The chapter also makes good use of the new university database schema to illustrate more complex design trade-offs.
- **Revised coverage of relational design.** Chapter 8 now has a more readable style, providing an intuitive understanding of functional dependencies and normalization, before covering functional dependency theory; the theory is motivated much better as a result.
- **Expanded material on application development and security.** Chapter 9 has new material on application development, mirroring rapid changes in the field. In particular, coverage of security has been expanded, considering its criticality in today's interconnected world, with an emphasis on practical issues over abstract concepts.
- **Revised and updated coverage of data storage, indexing and query optimization.** Chapter 10 has been updated with new technology, including expanded coverage of flash memory.

  Coverage of B^+-trees in Chapter 11 has been revised to reflect practical implementations, including coverage of bulk loading, and the presentation has been improved. The B^+-tree examples in Chapter 11 have now been revised with $n = 4$, to avoid the special case of empty nodes that arises with the (unrealistic) value of $n = 3$.

  Chapter 13 has new material on advanced query-optimization techniques.
- **Revised coverage of transaction management.** Chapter 14 provides full coverage of the basics for an introductory course, with advanced details following in Chapters 15 and 16. Chapter 14 has been expanded to cover the practical issues in transaction management faced by database users and database-application developers. The chapter also includes an expanded overview of topics covered in Chapters 15 and 16, ensuring that even if Chapters 15 and 16 are omitted, students have a basic knowledge of the concepts of concurrency control and recovery.

Chapters 14 and 15 now include detailed coverage of snapshot isolation, which is widely supported and used today, including coverage of potential hazards when using it.

Chapter 16 now has a simplified description of basic log-based recovery leading up to coverage of the ARIES algorithm.

- **Revised and expanded coverage of distributed databases.** We now cover cloud data storage, which is gaining significant interest for business applications. Cloud storage offers enterprises opportunities for improved cost-management and increased storage scalability, particularly for Web-based applications. We examine those advantages along with the potential drawbacks and risks.

  Multidatabases, which were earlier in the advanced transaction processing chapter, are now covered earlier as part of the distributed database chapter.

- **Postponed coverage of object databases and XML.** Although object-oriented languages and XML are widely used outside of databases, their use in databases is still limited, making them appropriate for more advanced courses, or as supplementary material for an introductory course. These topics have therefore been moved to later in the book, in Chapters 22 and 23.

- **QBE, Microsoft Access, and Datalog in an online appendix.** These topics, which were earlier part of a chapter on "other relational languages," are now covered in online Appendix C.

All topics not listed above are updated from the fifth edition, though their overall organization is relatively unchanged.

Review Material and Exercises

Each chapter has a list of review terms, in addition to a summary, which can help readers review key topics covered in the chapter.

The exercises are divided into two sets: **practice exercises** and **exercises**. The solutions for the practice exercises are publicly available on the Web site of the book. Students are encouraged to solve the practice exercises on their own, and later use the solutions on the Web site to check their own solutions. Solutions to the other exercises are available only to instructors (see "Instructor's Note," below, for information on how to get the solutions).

Many chapters have a tools section at the end of the chapter that provides information on software tools related to the topic of the chapter; some of these tools can be used for laboratory exercises. SQL DDL and sample data for the university database and other relations used in the exercises are available on the Web site of the book, and can be used for laboratory exercises.

Instructor's Note

The book contains both basic and advanced material, which might not be covered in a single semester. We have marked several sections as advanced, using the symbol "**". These sections may be omitted if so desired, without a loss of continuity. Exercises that are difficult (and can be omitted) are also marked using the symbol "**".

It is possible to design courses by using various subsets of the chapters. Some of the chapters can also be covered in an order different from their order in the book. We outline some of the possibilities here:

- Chapter 5 (Advanced SQL) can be skipped or deferred to later without loss of continuity. We expect most courses will cover at least Section 5.1.1 early, as JDBC is likely to be a useful tool in student projects.
- Chapter 6 (Formal Relational Query Languages) can be covered immediately after Chapter 2, ahead of SQL. Alternatively, this chapter may be omitted from an introductory course.

  We recommend covering Section 6.1 (relational algebra) if the course also covers query processing. However, Sections 6.2 and 6.3 can be omitted if students will not be using relational calculus as part of the course.
- Chapter 7 (E-R Model) can be covered ahead of Chapters 3, 4 and 5 if you so desire, since Chapter 7 does not have any dependency on SQL.
- Chapter 13 (Query Optimization) can be omitted from an introductory course without affecting coverage of any other chapter.
- Both our coverage of transaction processing (Chapters 14 through 16) and our coverage of system architecture (Chapters 17 through 19) consist of an overview chapter (Chapters 14 and 17, respectively), followed by chapters with details. You might choose to use Chapters 14 and 17, while omitting Chapters 15, 16, 18 and 19, if you defer these latter chapters to an advanced course.
- Chapters 20 and 21, covering data warehousing, data mining, and information retrieval, can be used as self-study material or omitted from an introductory course.
- Chapters 22 (Object-Based Databases), and 23 (XML) can be omitted from an introductory course.
- Chapters 24 through 26, covering advanced application development, spatial, temporal and mobile data, and advanced transaction processing, are suitable for an advanced course or for self-study by students.
- The case-study Chapters 27 through 30 are suitable for self-study by students. Alternatively, they can be used as an illustration of concepts when the earlier chapters are presented in class.

Model course syllabi, based on the text, can be found on the Web site of the book.

Web Site and Teaching Supplements

A Web site for the book is available at the URL: http://www.db-book.com. The Web site contains:

- Slides covering all the chapters of the book.
- Answers to the practice exercises.
- The five appendices.
- An up-to-date errata list.
- Laboratory material, including SQL DDL and sample data for the university schema and other relations used in exercises, and instructions for setting up and using various database systems and tools.

The following additional material is available only to faculty:

- An instructor manual containing solutions to all exercises in the book.
- A question bank containing extra exercises.

For more information about how to get a copy of the instructor manual and the question bank, please send electronic mail to customer.service@mcgraw-hill.com. In the United States, you may call 800-338-3987. The McGraw-Hill Web site for this book is http://www.mhhe.com/silberschatz.

Contacting Us

We have endeavored to eliminate typos, bugs, and the like from the text. But, as in new releases of software, bugs almost surely remain; an up-to-date errata list is accessible from the book's Web site. We would appreciate it if you would notify us of any errors or omissions in the book that are not on the current list of errata.

We would be glad to receive suggestions on improvements to the book. We also welcome any contributions to the book Web site that could be of use to other readers, such as programming exercises, project suggestions, online labs and tutorials, and teaching tips.

Email should be addressed to db-book-authors@cs.yale.edu. Any other correspondence should be sent to Avi Silberschatz, Department of Computer Science, Yale University, 51 Prospect Street, P.O. Box 208285, New Haven, CT 06520-8285 USA.

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Sixth Edition

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