FUNDAMENTALS OF

DATABASE SYSTEMS

7TH Edition

ELMASRI • NAVATHE

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Database Systems

SEVENTH EDITION

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Database Systems

SEVENTH EDITION

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To Amalia
and
to Ramy, Riyad, Katrina, and Thomas

R. E.

To my wife Aruna for her love, support, and understanding
and
to Rohan, Maya, and Ayush for bringing so much joy into our lives

S.B.N.

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Preface

This book introduces the fundamental concepts necessary for designing, using, and implementing database systems and database applications. Our presentation stresses the fundamentals of database modeling and design, the languages and models provided by the database management systems, and database system implementation techniques. The book is meant to be used as a textbook for a one- or two-semester course in database systems at the junior, senior, or graduate level, and as a reference book. Our goal is to provide an in-depth and up-to-date presentation of the most important aspects of database systems and applications, and related technologies. We assume that readers are familiar with elementary programming and data-structuring concepts and that they have had some exposure to the basics of computer organization.

New to This Edition

The following key features have been added in the seventh edition:

- A reorganization of the chapter ordering (this was based on a survey of the instructors who use the textbook); however, the book is still organized so that the individual instructor can choose to follow the new chapter ordering or *choose a different ordering of chapters* (for example, follow the chapter order from the sixth edition) when presenting the materials.
- There are two new chapters on recent advances in database systems and big data processing; one new chapter (Chapter 24) covers an introduction to the newer class of database systems known as **NOSQL databases**, and the other new chapter (Chapter 25) covers technologies for processing **big data**, including **MapReduce** and **Hadoop.**
- The chapter on query processing and optimization has been expanded and reorganized into two chapters; Chapter 18 focuses on strategies and algorithms for query processing whereas Chapter 19 focuses on query optimization techniques.
- A second UNIVERSITY database example has been added to the early chapters (Chapters 3 through 8) in addition to our COMPANY database example from the previous editions.
- Many of the individual chapters have been updated to varying degrees to include newer techniques and methods; rather than discuss these enhancements here,

we will describe them later in the preface when we discuss the organization of the seventh edition.

The following are key features of the book:

- A self-contained, flexible organization that can be tailored to individual needs; in particular, *the chapters can be used in different orders* depending on the instructor's preference.
- A companion website (http://www.pearsonhighered.com/cs-resources) includes data to be loaded into various types of relational databases for more realistic student laboratory exercises.
- A dependency chart (shown later in this preface) to show which chapters depend on other earlier chapters; this can guide the instructor who wants to tailor the *order of presentation of the chapters*.
- A collection of supplements, including a robust set of materials for instructors and students such as PowerPoint slides, figures from the text, and an instructor's guide with solutions.

Organization and Contents of the Seventh Edition

There are some organizational changes in the seventh edition as well as improvement to the individual chapters. The book is now divided into 12 parts as follows:

- Part 1 (Chapters 1 and 2) describes the basic introductory concepts necessary for a good understanding of database models, systems, and languages. Chapters 1 and 2 introduce databases, typical users, and DBMS concepts, terminology, and architecture, as well as a discussion of the progression of database technologies over time and a brief history of data models. These chapters have been updated to introduce some of the newer technologies such as NOSQL systems.
- Part 2 (Chapters 3 and 4) includes the presentation on entity-relationship modeling and database design; however, it is *important to note* that instructors can cover the relational model chapters (Chapters 5 through 8) *before Chapters 3 and 4* if that is their preferred order of presenting the course materials. In Chapter 3, the concepts of the Entity-Relationship (ER) model and ER diagrams are presented and used to illustrate conceptual database design. Chapter 4 shows how the basic ER model can be extended to incorporate additional modeling concepts such as subclasses, specialization, generalization, union types (categories) and inheritance, leading to the enhanced-ER (EER) data model and EER diagrams. The notation for the class diagrams of UML are also introduced in Chapters 7 and 8 as an alternative model and diagrammatic notation for ER/EER diagrams.
- Part 3 (Chapters 5 through 8) includes a detailed presentation on relational databases and SQL with some additional new material in the SQL chapters to cover a few SQL constructs that were not in the previous edition. Chapter 5

describes the basic relational model, its integrity constraints, and update operations. Chapter 6 describes some of the basic parts of the SQL standard for relational databases, including data definition, data modification operations, and simple SQL queries. Chapter 7 presents more complex SQL queries, as well as the SQL concepts of triggers, assertions, views, and schema modification. Chapter 8 describes the formal operations of the relational algebra and introduces the relational calculus. The material on SQL (Chapters 6 and 7) is presented before our presentation on relational algebra and calculus in Chapter 8 to allow instructors to start SQL projects early in a course if they wish (it is possible to cover Chapter 8 before Chapters 6 and 7 if the instructor desires this order). The final chapter in Part 2, Chapter 9, covers ER- and EER-to-relational mapping, which are algorithms that can be used for designing a relational database schema from a conceptual ER/EER schema design.

- Part 4 (Chapters 10 and 11) are the chapters on database programming techniques; these chapters can be assigned as reading materials and augmented with materials on the particular language used in the course for programming projects (much of this documentation is readily available on the Web). Chapter 10 covers traditional SQL programming topics, such as embedded SQL, dynamic SQL, ODBC, SQLJ, JDBC, and SQL/CLI. Chapter 11 introduces Web database programming, using the PHP scripting language in our examples, and includes new material that discusses Java technologies for Web database programming.
- Part 5 (Chapters 12 and 13) covers the updated material on object-relational and object-oriented databases (Chapter 12) and XML (Chapter 13); both of these chapters now include a presentation of how the SQL standard incorporates object concepts and XML concepts into more recent versions of the SQL standard. Chapter 12 first introduces the concepts for object databases, and then shows how they have been incorporated into the SQL standard in order to add object capabilities to relational database systems. It then covers the ODMG object model standard, and its object definition and query languages. Chapter 13 covers the XML (eXtensible Markup Language) model and languages, and discusses how XML is related to database systems. It presents XML concepts and languages, and compares the XML model to traditional database models. We also show how data can be converted between the XML and relational representations, and the SQL commands for extracting XML documents from relational tables.
- Part 6 (Chapters 14 and 15) are the normalization and relational design theory chapters (we moved all the formal aspects of normalization algorithms to Chapter 15). Chapter 14 defines functional dependencies, and the normal forms that are based on functional dependencies. Chapter 14 also develops a step-by-step intuitive normalization approach, and includes the definitions of multivalued dependencies and join dependencies. Chapter 15 covers normalization theory, and the formalisms, theories,

and algorithms developed for relational database design by normalization, including the relational decomposition algorithms and the relational synthesis algorithms.

- Part 7 (Chapters 16 and 17) contains the chapters on file organizations on disk (Chapter 16) and indexing of database files (Chapter 17). Chapter 16 describes primary methods of organizing files of records on disk, including ordered (sorted), unordered (heap), and hashed files; both static and dynamic hashing techniques for disk files are covered. Chapter 16 has been updated to include materials on buffer management strategies for DBMSs as well as an overview of new storage devices and standards for files and modern storage architectures. Chapter 17 describes indexing techniques for files, including B-tree and B^+-tree data structures and grid files, and has been updated with new examples and an enhanced discussion on indexing, including how to choose appropriate indexes and index creation during physical design.
- Part 8 (Chapters 18 and 19) includes the chapters on query processing algorithms (Chapter 18) and optimization techniques (Chapter 19); these two chapters have been updated and reorganized from the single chapter that covered both topics in the previous editions and include some of the newer techniques that are used in commercial DBMSs. Chapter 18 presents algorithms for searching for records on disk files, and for joining records from two files (tables), as well as for other relational operations. Chapter 18 contains new material, including a discussion of the semi-join and anti-join operations with examples of how they are used in query processing, as well as a discussion of techniques for selectivity estimation. Chapter 19 covers techniques for query optimization using cost estimation and heuristic rules; it includes new material on nested subquery optimization, use of histograms, physical optimization, and join ordering methods and optimization of typical queries in data warehouses.
- Part 9 (Chapters 20, 21, and 22) covers transaction processing concepts; concurrency control; and database recovery from failures. These chapters have been updated to include some of the newer techniques that are used in some commercial and open source DBMSs. Chapter 20 introduces the techniques needed for transaction processing systems, and defines the concepts of recoverability and serializability of schedules; it has a new section on buffer replacement policies for DBMSs and a new discussion on the concept of snapshot isolation. Chapter 21 gives an overview of the various types of concurrency control protocols, with a focus on two-phase locking. We also discuss timestamp ordering and optimistic concurrency control techniques, as well as multiple-granularity locking. Chapter 21 includes a new presentation of concurrency control methods that are based on the snapshot isolation concept. Finally, Chapter 23 focuses on database recovery protocols, and gives an overview of the concepts and techniques that are used in recovery.

- Part 10 (Chapters 23, 24, and 25) includes the chapter on distributed databases (Chapter 23), plus the two new chapters on NOSQL storage systems for big data (Chapter 24) and big data technologies based on Hadoop and MapReduce (Chapter 25). Chapter 23 introduces distributed database concepts, including availability and scalability, replication and fragmentation of data, maintaining data consistency among replicas, and many other concepts and techniques. In Chapter 24, NOSQL systems are categorized into four general categories with an example system in each category used for our examples, and the data models, operations, as well as the replication/distribution/scalability strategies of each type of NOSQL system are discussed and compared. In Chapter 25, the MapReduce programming model for distributed processing of big data is introduced, and then we have presentations of the Hadoop system and HDFS (Hadoop Distributed File System), as well as the Pig and Hive high-level interfaces, and the YARN architecture.
- Part 11 (Chapters 26 through 29) is entitled Advanced Database Models, Systems, and Applications and includes the following materials: Chapter 26 introduces several advanced data models including active databases/triggers (Section 26.1), temporal databases (Section 26.2), spatial databases (Section 26.3), multimedia databases (Section 26.4), and deductive databases (Section 26.5). Chapter 27 discusses information retrieval (IR) and Web search, and includes topics such as IR and keyword-based search, comparing DB with IR, retrieval models, search evaluation, and ranking algorithms. Chapter 28 is an introduction to data mining including overviews of various data mining methods such as associate rule mining, clustering, classification, and sequential pattern discovery. Chapter 29 is an overview of data warehousing including topics such as data warehousing models and operations, and the process of building a data warehouse.
- Part 12 (Chapter 30) includes one chapter on database security, which includes a discussion of SQL commands for discretionary access control (GRANT, REVOKE), as well as mandatory security levels and models for including mandatory access control in relational databases, and a discussion of threats such as SQL injection attacks, as well as other techniques and methods related to data security and privacy.

Appendix A gives a number of alternative diagrammatic notations for displaying a conceptual ER or EER schema. These may be substituted for the notation we use, if the instructor prefers. Appendix B gives some important physical parameters of disks. Appendix C gives an overview of the QBE graphical query language, and Appendixes D and E (available on the book's Companion Website located at http://www.pearsonhighered.com/elmasri) cover legacy database systems, based on the hierarchical and network database models. They have been used for more than thirty years as a basis for many commercial database applications and transaction-processing systems.

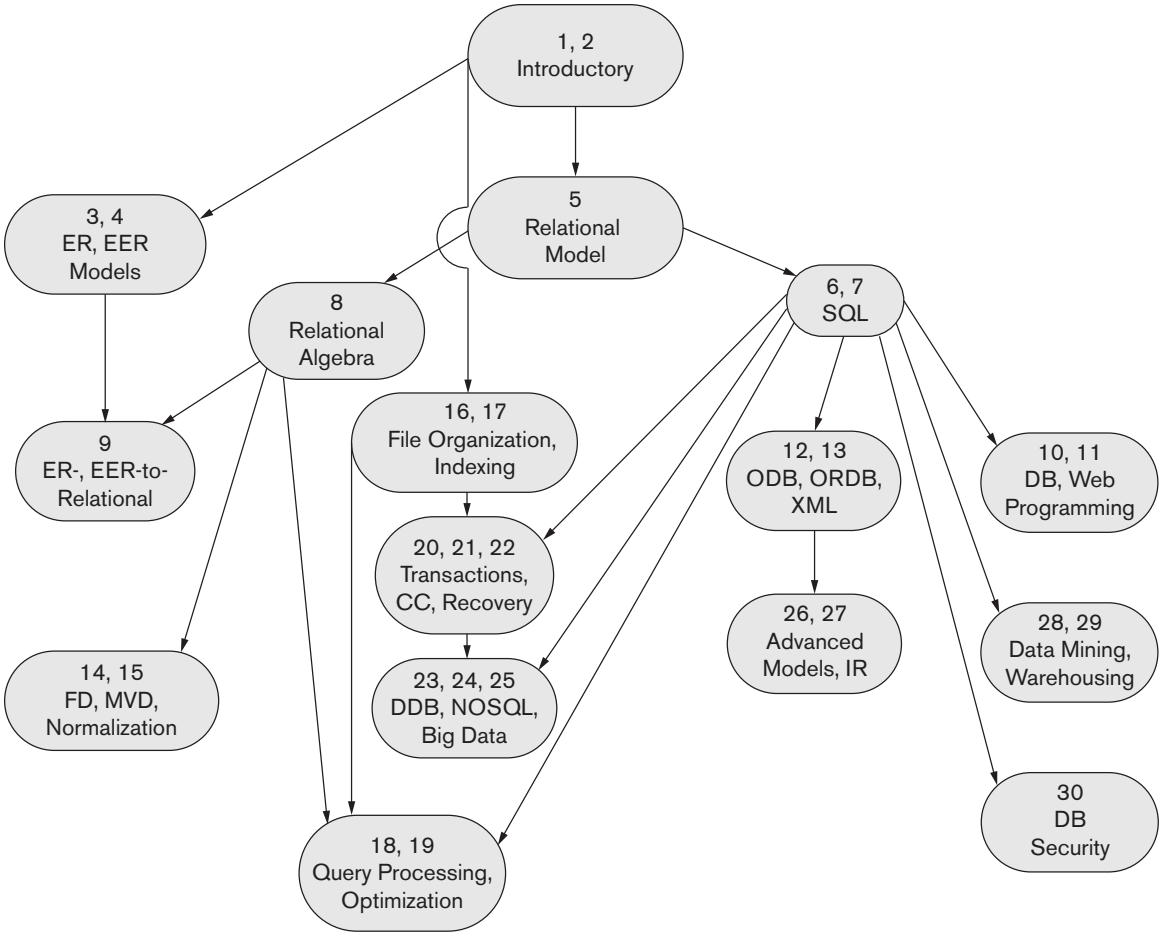
Guidelines for Using This Book

There are many different ways to teach a database course. The chapters in Parts 1 through 7 can be used in an introductory course on database systems in the order that they are given or in the preferred order of individual instructors. Selected chapters and sections may be left out and the instructor can add other chapters from the rest of the book, depending on the emphasis of the course. At the end of the opening section of some of the book's chapters, we list sections that are candidates for being left out whenever a less-detailed discussion of the topic is desired. We suggest covering up to Chapter 15 in an introductory database course and including selected parts of other chapters, depending on the background of the students and the desired coverage. For an emphasis on system implementation techniques, chapters from Parts 7, 8, and 9 should replace some of the earlier chapters.

Chapters 3 and 4, which cover conceptual modeling using the ER and EER models, are important for a good conceptual understanding of databases. However, they may be partially covered, covered later in a course, or even left out if the emphasis is on DBMS implementation. Chapters 16 and 17 on file organizations and indexing may also be covered early, later, or even left out if the emphasis is on database models and languages. For students who have completed a course on file organization, parts of these chapters can be assigned as reading material or some exercises can be assigned as a review for these concepts.

If the emphasis of a course is on database design, then the instructor should cover Chapters 3 and 4 early on, followed by the presentation of relational databases. A total life-cycle database design and implementation project would cover conceptual design (Chapters 3 and 4), relational databases (Chapters 5, 6, and 7), data model mapping (Chapter 9), normalization (Chapter 14), and application programs implementation with SQL (Chapter 10). Chapter 11 also should be covered if the emphasis is on Web database programming and applications. Additional documentation on the specific programming languages and RDBMS used would be required. The book is written so that it is possible to cover topics in various sequences. The following chapter dependency chart shows the major dependencies among chapters. As the diagram illustrates, it is possible to start with several different topics following the first two introductory chapters. Although the chart may seem complex, it is important to note that if the chapters are covered in order, the dependencies are not lost. The chart can be consulted by instructors wishing to use an alternative order of presentation.

For a one-semester course based on this book, selected chapters can be assigned as reading material. The book also can be used for a two-semester course sequence. The first course, *Introduction to Database Design and Database Systems*, at the sophomore, junior, or senior level, can cover most of Chapters 1 through 15. The second course, *Database Models and Implementation Techniques*, at the senior or first-year graduate level, can cover most of Chapters 16 through 30. The two-semester sequence can also be designed in various other ways, depending on the preferences of the instructors.



Supplemental Materials

Support material is available to qualified instructors at Pearson's instructor resource center (http://www.pearsonhighered.com/irc). For access, contact your local Pearson representative.

- PowerPoint lecture notes and figures.
- A solutions manual.

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