Sixth Edition

Fundamentals of Database Systems

Elmasri • Navathe

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Database Systems

SIXTH EDITION

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Database Systems

SIXTH EDITION

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To Katrina, Thomas, and Dora
(and also to Ficky)

R. E.

To my wife Aruna, mother Vijaya,
and to my entire family
for their love and support

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 sixth edition:

- A reorganization of the chapter ordering to allow instructors to start with projects and laboratory exercises very early in the course
- The material on SQL, the relational database standard, has been moved early in the book to Chapters 4 and 5 to allow instructors to focus on this important topic at the beginning of a course
- The material on object-relational and object-oriented databases has been updated to conform to the latest SQL and ODMG standards, and consolidated into a single chapter (Chapter 11)
- The presentation of XML has been expanded and updated, and moved earlier in the book to Chapter 12
- The chapters on normalization theory have been reorganized so that the first chapter (Chapter 15) focuses on intuitive normalization concepts, while the second chapter (Chapter 16) focuses on the formal theories and normalization algorithms
- The presentation of database security threats has been updated with a discussion on SQL injection attacks and prevention techniques in Chapter 24, and an overview of label-based security with examples

- Our presentation on spatial databases and multimedia databases has been expanded and updated in Chapter 26
- A new Chapter 27 on information retrieval techniques has been added, which discusses models and techniques for retrieval, querying, browsing, and indexing of information from Web documents; we present the typical processing steps in an information retrieval system, the evaluation metrics, and how information retrieval techniques are related to databases and to Web search

The following are key features of the book:

- A self-contained, flexible organization that can be tailored to individual needs
- A Companion Website (http://www.aw.com/elmasri) includes data to be loaded into various types of relational databases for more realistic student laboratory exercises
- A simple relational algebra and calculus interpreter
- 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 of the Sixth Edition

There are significant organizational changes in the sixth edition, as well as improvement to the individual chapters. The book is now divided into eleven parts as follows:

- Part 1 (Chapters 1 and 2) includes the introductory chapters
- The presentation on relational databases and SQL has been moved to Part 2 (Chapters 3 through 6) of the book; Chapter 3 presents the formal relational model and relational database constraints; the material on SQL (Chapters 4 and 5) is now presented before our presentation on relational algebra and calculus in Chapter 6 to allow instructors to start SQL projects early in a course if they wish (this reordering is also based on a study that suggests students master SQL better when it is taught before the formal relational languages)
- The presentation on entity-relationship modeling and database design is now in Part 3 (Chapters 7 through 10), but it can still be covered before Part 2 if the focus of a course is on database design
- Part 4 covers the updated material on object-relational and object-oriented databases (Chapter 11) and XML (Chapter 12)
- Part 5 includes the chapters on database programming techniques (Chapter 13) and Web database programming using PHP (Chapter 14, which was moved earlier in the book)
- Part 6 (Chapters 15 and 16) are the normalization and design theory chapters (we moved all the formal aspects of normalization algorithms to Chapter 16)

- Part 7 (Chapters 17 and 18) contains the chapters on file organizations, indexing, and hashing
- Part 8 includes the chapters on query processing and optimization techniques (Chapter 19) and database tuning (Chapter 20)
- Part 9 includes Chapter 21 on transaction processing concepts; Chapter 22 on concurrency control; and Chapter 23 on database recovery from failures
- Part 10 on additional database topics includes Chapter 24 on database security and Chapter 25 on distributed databases
- Part 11 on advanced database models and applications includes Chapter 26 on advanced data models (active, temporal, spatial, multimedia, and deductive databases); the new Chapter 27 on information retrieval and Web search; and the chapters on data mining (Chapter 28) and data warehousing (Chapter 29)

Contents of the Sixth Edition

Part 1 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.

Part 2 describes the relational data model, the SQL standard, and the formal relational languages. Chapter 3 describes the basic relational model, its integrity constraints, and update operations. Chapter 4 describes some of the basic parts of the SQL standard for relational databases, including data definition, data modification operations, and simple SQL queries. Chapter 5 presents more complex SQL queries, as well as the SQL concepts of triggers, assertions, views, and schema modification. Chapter 6 describes the operations of the relational algebra and introduces the relational calculus.

Part 3 covers several topics related to conceptual database modeling and database design. In Chapter 7, the concepts of the Entity-Relationship (ER) model and ER diagrams are presented and used to illustrate conceptual database design. Chapter 8 focuses on data abstraction and semantic data modeling concepts and shows how the ER model can be extended to incorporate these ideas, leading to the enhanced-ER (EER) data model and EER diagrams. The concepts presented in Chapter 8 include subclasses, specialization, generalization, and union types (categories). The notation for the class diagrams of UML is also introduced in Chapters 7 and 8. Chapter 9 discusses relational database design using ER- and EER-to-relational mapping. We end Part 3 with Chapter 10, which presents an overview of the different phases of the database design process in enterprises for medium-sized and large database applications.

Part 4 covers the object-oriented, object-relational, and XML data models, and their affiliated languages and standards. Chapter 11 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 12 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.

Part 5 is on database programming techniques. Chapter 13 covers SQL programming topics, such as embedded SQL, dynamic SQL, ODBC, SQLJ, JDBC, and SQL/CLI. Chapter 14 introduces Web database programming, using the PHP scripting language in our examples.

Part 6 covers normalization theory. Chapters 15 and 16 cover the formalisms, theories, and algorithms developed for relational database design by normalization. This material includes functional and other types of dependencies and normal forms of relations. Step-by-step intuitive normalization is presented in Chapter 15, which also defines multivalued and join dependencies. Relational design algorithms based on normalization, along with the theoretical materials that the algorithms are based on, are presented in Chapter 16.

Part 7 describes the physical file structures and access methods used in database systems. Chapter 17 describes primary methods of organizing files of records on disk, including static and dynamic hashing. Chapter 18 describes indexing techniques for files, including B-tree and B^+-tree data structures and grid files.

Part 8 focuses on query processing and database performance tuning. Chapter 19 introduces the basics of query processing and optimization, and Chapter 20 discusses physical database design and tuning.

Part 9 discusses transaction processing, concurrency control, and recovery techniques, including discussions of how these concepts are realized in SQL. Chapter 21 introduces the techniques needed for transaction processing systems, and defines the concepts of recoverability and serializability of schedules. Chapter 22 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. Finally, Chapter 23 focuses on database recovery protocols, and gives an overview of the concepts and techniques that are used in recovery.

Parts 10 and 11 cover a number of advanced topics. Chapter 24 gives an overview of database security including the discretionary access control model with SQL commands to GRANT and REVOKE privileges, the mandatory access control model with user categories and polyinstantiation, a discussion of data privacy and its relationship to security, and an overview of SQL injection attacks. Chapter 25 gives an introduction to distributed databases and discusses the three-tier client/server architecture. Chapter 26 introduces several enhanced database models for advanced applications. These include active databases and triggers, as well as temporal, spatial, multimedia, and deductive databases. Chapter 27 is a new chapter on information retrieval techniques, and how they are related to database systems and to Web

search methods. Chapter 28 on data mining gives an overview of the process of data mining and knowledge discovery, discusses algorithms for association rule mining, classification, and clustering, and briefly covers other approaches and commercial tools. Chapter 29 introduces data warehousing and OLAP concepts.

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. Appendixes D and E (available on the book's Companion Website located at http://www.aw.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. We consider it important to expose database management students to these legacy approaches so they can gain a better insight of how database technology has progressed.

Guidelines for Using This Book

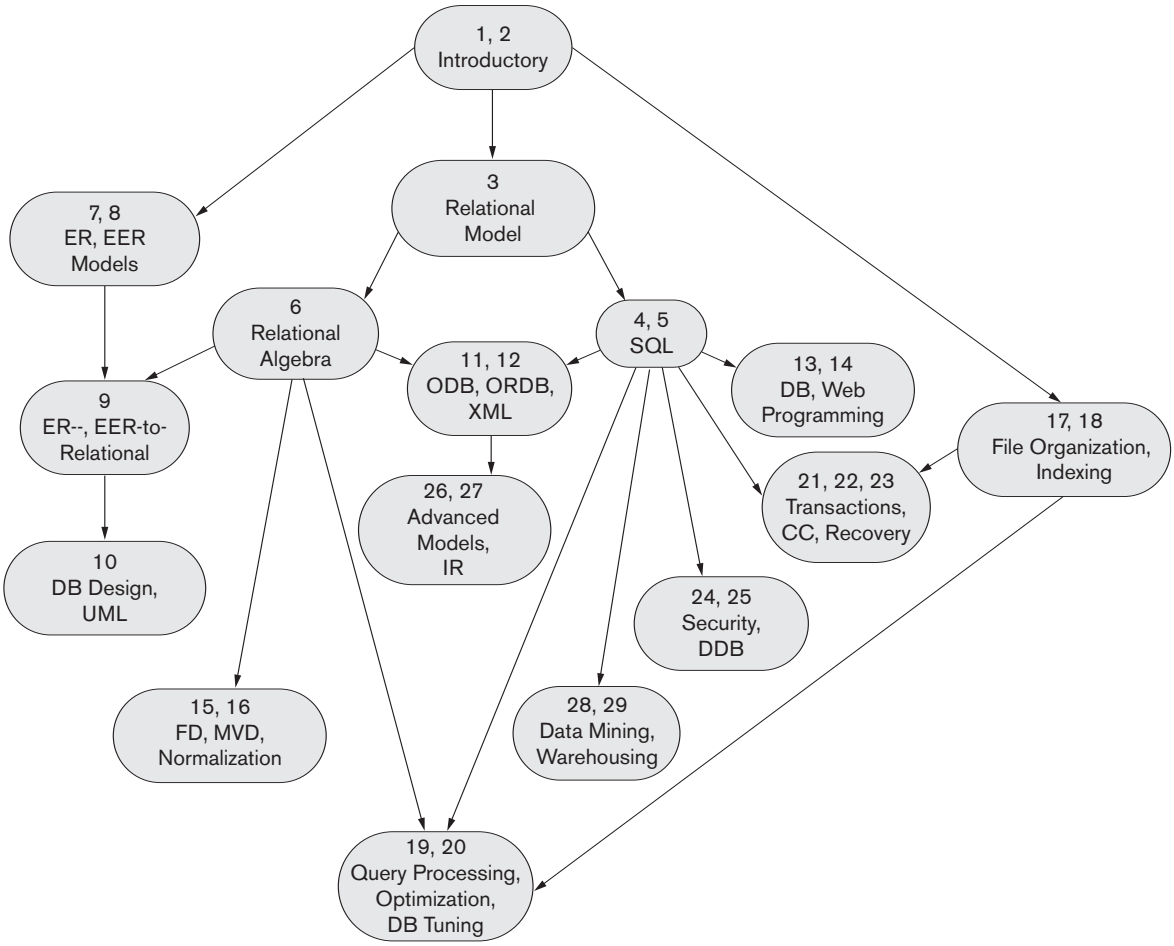
There are many different ways to teach a database course. The chapters in Parts 1 through 7 can be used in an introductory course on database systems in the order that they are given or in the preferred order of individual instructors. Selected chapters and sections may be left out, and the instructor 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 many 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 7 and 8, 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 17 and 18 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 7 and 8 early on, followed by the presentation of relational databases. A total life-cycle database design and implementation project would cover conceptual design (Chapters 7 and 8), relational databases (Chapters 3, 4, and 5), data model mapping (Chapter 9), normalization (Chapter 15), and application programs implementation with SQL (Chapter 13). Chapter 14 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 chapter dependency chart below 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 29. The two-semester sequence can also been designed in various other ways, depending on the preferences of the instructors.



Supplemental Materials

Support material is available to all users of this book and additional material is available to qualified instructors.

- PowerPoint lecture notes and figures are available at the Computer Science support Website at http://www.aw.com/cssupport.
- A lab manual for the sixth edition is available through the Companion Website (http://www.aw.com/elmasri). The lab manual contains coverage of popular data modeling tools, a relational algebra and calculus interpreter, and examples from the book implemented using two widely available database management systems. Select end-of-chapter laboratory problems in the book are correlated to the lab manual.
- A solutions manual is available to qualified instructors. Visit Addison-Wesley's instructor resource center (http://www.aw.com/irc), contact your local Addison-Wesley sales representative, or e-mail computing@aw.com for information about how to access the solutions.

Additional Support Material

Gradiance, an online homework and tutorial system that provides additional practice and tests comprehension of important concepts, is available to U.S. adopters of this book. For more information, please e-mail computing@aw.com or contact your local Pearson representative.

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S.B.N.

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part 1

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