

# Contents

## Preface xvii

### Chapter 1 Introduction

- |  |    |  |    |
|--|----|--|----|
| 1.1 Database-System Applications                 | 1  | 1.9 Transaction Management             | 22 |
| 1.2 Purpose of Database Systems                  | 3  | 1.10 Data Mining and Analysis          | 23 |
| 1.3 View of Data                                 | 5  | 1.11 Database Architecture             | 24 |
| 1.4 Database Languages                           | 9  | 1.12 Database Users and Administrators | 26 |
| 1.5 Relational Databases                         | 11 | 1.13 History of Database Systems       | 28 |
| 1.6 Database Design                              | 14 | 1.14 Summary                           | 30 |
| 1.7 Object-Based and Semistructured<br>Databases | 19 | Exercises                              | 31 |
| 1.8 Data Storage and Querying                    | 20 | Bibliographical Notes                  | 32 |

## PART 1 ■ RELATIONAL DATABASES

### Chapter 2 Relational Model

- |  |    |                                  |    |
|--|----|----------------------------------|----|
| 2.1 Structure of Relational Databases            | 37 | 2.5 Null Values                  | 66 |
| 2.2 Fundamental Relational-Algebra<br>Operations | 46 | 2.6 Modification of the Database | 68 |
| 2.3 Additional Relational-Algebra<br>Operations  | 55 | 2.7 Summary                      | 70 |
| 2.4 Extended Relational-Algebra<br>Operations    | 60 | Exercises                        | 71 |
|  |    | Bibliographical Notes            | 73 |

## Chapter 3 SQL

- 3.1 Background 75
- 3.2 Data Definition 77
- 3.3 Basic Structure of SQL Queries 80
- 3.4 Set Operations 87
- 3.5 Aggregate Functions 89
- 3.6 Null Values 91
- 3.7 Nested Subqueries 93
- 3.8 Complex Queries 97
- 3.9 Views 99
- 3.10 Modification of the Database 103
- 3.11 Joined Relations\*\* 110
- 3.12 Summary 115
  - Exercises 116
  - Bibliographical Notes 120

## Chapter 4 Advanced SQL

- 4.1 SQL Data Types and Schemas 121
- 4.2 Integrity Constraints 126
- 4.3 Authorization 133
- 4.4 Embedded SQL 134
- 4.5 Dynamic SQL 137
- 4.6 Functions and Procedural Constructs\*\* 145
- 4.7 Recursive Queries\*\* 151
- 4.8 Advanced SQL Features\*\* 155
- 4.9 Summary 158
  - Exercises 159
  - Bibliographical Notes 162

## Chapter 5 Other Relational Languages

- 5.1 The Tuple Relational Calculus 163
- 5.2 The Domain Relational Calculus 168
- 5.3 Query-by-Example 171
- 5.4 Datalog 180
- 5.5 Summary 194
  - Exercises 195
  - Bibliographical Notes 198

# PART 2 ■ DATABASE DESIGN

## Chapter 6 Database Design and the E-R Model

- 6.1 Overview of the Design Process 201
- 6.2 The Entity-Relationship Model 204
- 6.3 Constraints 210
- 6.4 Entity-Relationship Diagrams 214
- 6.5 Entity-Relationship Design Issues 220
- 6.6 Weak Entity Sets 225
- 6.7 Extended E-R Features 227
- 6.8 Database Design for Banking Enterprise 236
- 6.9 Reduction to Relational Schemas 241
- 6.10 Other Aspects of Database Design 248
- 6.11 The Unified Modeling Language UML\*\* 251
- 6.12 Summary 254
  - Exercises 256
  - Bibliographical Notes 261

## Chapter 7 Relational Database Design

- |   |  |
|---|--|
| 7.1 Features of Good Relational Designs 263         | 7.6 Decomposition Using Multivalued Dependencies 293 |
| 7.2 Atomic Domains and First Normal Form 268        | 7.7 More Normal Forms 298                            |
| 7.3 Decomposition Using Functional Dependencies 270 | 7.8 Database-Design Process 299                      |
| 7.4 Functional-Dependency Theory 278                | 7.9 Modeling Temporal Data 302                       |
| 7.5 Decomposition Using Functional Dependencies 288 | 7.10 Summary 304                                     |
|   | Exercises 306  |
|   | Bibliographical Notes 310                            |

## Chapter 8 Application Design and Development

- |   |                              |
|---|------------------------------|
| 8.1 User Interfaces and Tools 311       | 8.7 Authorization in SQL 335 |
| 8.2 Web Interfaces to Databases 314     | 8.8 Application Security 343 |
| 8.3 Web Fundamentals 315                | 8.9 Summary 350              |
| 8.4 Servlets and JSP 321                | Exercises 352                |
| 8.5 Building Large Web Applications 326 | Bibliographical Notes 357    |
| 8.6 Triggers 329                        |                              |

## PART 3 ■ OBJECT-BASED DATABASES AND XML

### Chapter 9 Object-Based Databases

- |  |  |
|--|--|
| 9.1 Overview 361                                   | 9.7 Implementing O-R Features 378                |
| 9.2 Complex Data Types 362                         | 9.8 Persistent Programming Languages 379         |
| 9.3 Structured Types and Inheritance in SQL 365    | 9.9 Object-Oriented versus Object-Relational 387 |
| 9.4 Table Inheritance 369                          | 9.10 Summary 388                                 |
| 9.5 Array and Multiset Types in SQL 371            | Exercises 389                                    |
| 9.6 Object-Identity and Reference Types in SQL 376 | Bibliographical Notes 393                        |

### Chapter 10 XML

- |  |                              |
|--|------------------------------|
| 10.1 Motivation 395                            | 10.6 Storage of XML Data 421 |
| 10.2 Structure of XML Data 399                 | 10.7 XML Applications 428    |
| 10.3 XML Document Schema 402                   | 10.8 Summary 431             |
| 10.4 Querying and Transformation 408           | Exercises 433                |
| 10.5 Application Program Interfaces to XML 420 | Bibliographical Notes 436    |

## PART 4 ■ DATA STORAGE AND QUERYING

### Chapter 11 Storage and File Structure

- 11.1 Overview of Physical Storage  
Media 441
- 11.2 Magnetic Disks 444
- 11.3 RAID 450
- 11.4 Tertiary Storage 458
- 11.5 Storage Access 460
- 11.6 File Organization 464
- 11.7 Organization of Records in Files 468
- 11.8 Data-Dictionary Storage 472
- 11.9 Summary 474  
Exercises 476  
Bibliographical Notes 478

### Chapter 12 Indexing and Hashing

- 12.1 Basic Concepts 481
- 12.2 Ordered Indices 482
- 12.3 B<sup>+</sup>-Tree Index Files 489
- 12.4 B-Tree Index Files 501
- 12.5 Multiple-Key Access 502
- 12.6 Static Hashing 506
- 12.7 Dynamic Hashing 511
- 12.8 Comparison of Ordered Indexing and Hashing 518
- 12.9 Bitmap Indices 520
- 12.10 Index Definition in SQL 523
- 12.11 Summary 524  
Exercises 526  
Bibliographical Notes 529

### Chapter 13 Query Processing

- 13.1 Overview 531
- 13.2 Measures of Query Cost 533
- 13.3 Selection Operation 534
- 13.4 Sorting 539
- 13.5 Join Operation 542
- 13.6 Other Operations 555
- 13.7 Evaluation of Expressions 559
- 13.8 Summary 563  
Exercises 566  
Bibliographical Notes 568

### Chapter 14 Query Optimization

- 14.1 Overview 569
- 14.2 Transformation of Relational Expressions 571
- 14.3 Estimating Statistics of Expression Results 578
- 14.4 Choice of Evaluation Plans 584
- 14.5 Materialized Views\*\* 593
- 14.6 Summary 598  
Exercises 599  
Bibliographical Notes 602

## PART 5 ■ TRANSACTION MANAGEMENT

### Chapter 15 Transactions

- |   |     |                                  |     |
|---|-----|----------------------------------|-----|
| 15.1 Transaction Concept                        | 609 | 15.6 Recoverability              | 626 |
| 15.2 Transaction State                          | 612 | 15.7 Implementation of Isolation | 627 |
| 15.3 Implementation of Atomicity and Durability | 615 | 15.8 Testing for Serializability | 628 |
| 15.4 Concurrent Executions                      | 617 | 15.9 Summary                     | 630 |
| 15.5 Serializability                            | 620 | Exercises                        | 632 |
|   |     | Bibliographical Notes            | 633 |

### Chapter 16 Concurrency Control

- |                                 |     |  |     |
|---------------------------------|-----|--|-----|
| 16.1 Lock-Based Protocols       | 635 | 16.7 Insert and Delete Operations      | 664 |
| 16.2 Timestamp-Based Protocols  | 648 | 16.8 Weak Levels of Consistency        | 667 |
| 16.3 Validation-Based Protocols | 651 | 16.9 Concurrency in Index Structures** | 669 |
| 16.4 Multiple Granularity       | 653 | 16.10 Summary                          | 673 |
| 16.5 Multiversion Schemes       | 656 | Exercises                              | 676 |
| 16.6 Deadlock Handling          | 659 | Bibliographical Notes                  | 680 |

### Chapter 17 Recovery System

- |  |     |   |     |
|--|-----|---|-----|
| 17.1 Failure Classification                | 683 | 17.7 Failure with Loss of Nonvolatile Storage | 702 |
| 17.2 Storage Structure                     | 684 | 17.8 Advanced Recovery Techniques**           | 703 |
| 17.3 Recovery and Atomicity                | 688 | 17.9 Remote Backup Systems                    | 711 |
| 17.4 Log-Based Recovery                    | 689 | 17.10 Summary                                 | 713 |
| 17.5 Recovery with Concurrent Transactions | 697 | Exercises                                     | 716 |
| 17.6 Buffer Management                     | 699 | Bibliographical Notes                         | 718 |

## PART 6 ■ DATA MINING AND INFORMATION RETRIEVAL

### Chapter 18 Data Analysis and Mining

- |                               |     |                       |     |
|-------------------------------|-----|-----------------------|-----|
| 18.1 Decision-Support Systems | 723 | 18.5 Summary          | 752 |
| 18.2 Data Analysis and OLAP   | 725 | Exercises             | 754 |
| 18.3 Data Warehousing         | 736 | Bibliographical Notes | 756 |
| 18.4 Data Mining              | 739 |                       |     |

## Chapter 19 Information Retrieval

- |  |     |  |     |
|--|-----|--|-----|
| 19.1 Overview                          | 759 | 19.7 Web Search Engines                        | 771 |
| 19.2 Relevance Ranking Using Terms     | 761 | 19.8 Information Retrieval and Structured Data | 772 |
| 19.3 Relevance Using Hyperlinks        | 763 | 19.9 Directories                               | 773 |
| 19.4 Synonyms, Homonyms and Ontologies | 768 | 19.10 Summary                                  | 776 |
| 19.5 Indexing of Documents             | 769 | Exercises                                      | 777 |
| 19.6 Measuring Retrieval Effectiveness | 770 | Bibliographical Notes                          | 779 |

## PART 7 ■ SYSTEM ARCHITECTURE

### Chapter 20 Database-System Architectures

- |  |     |                       |     |
|--|-----|-----------------------|-----|
| 20.1 Centralized and Client–Server Architectures | 783 | 20.5 Network Types    | 801 |
| 20.2 Server System Architectures                 | 786 | 20.6 Summary          | 803 |
| 20.3 Parallel Systems                            | 790 | Exercises             | 805 |
| 20.4 Distributed Systems                         | 797 | Bibliographical Notes | 807 |

### Chapter 21 Parallel Databases

- |                                 |     |                                 |     |
|---------------------------------|-----|---------------------------------|-----|
| 21.1 Introduction               | 809 | 21.6 Interoperation Parallelism | 824 |
| 21.2 I/O Parallelism            | 810 | 21.7 Design of Parallel Systems | 826 |
| 21.3 Interquery Parallelism     | 814 | 21.8 Summary                    | 827 |
| 21.4 Intraquery Parallelism     | 815 | Exercises                       | 829 |
| 21.5 Intraoperation Parallelism | 816 | Bibliographical Notes           | 831 |

### Chapter 22 Distributed Databases

- |   |     |  |     |
|---|-----|--|-----|
| 22.1 Homogeneous and Heterogeneous Databases      | 833 | 22.7 Distributed Query Processing        | 859 |
| 22.2 Distributed Data Storage                     | 834 | 22.8 Heterogeneous Distributed Databases | 862 |
| 22.3 Distributed Transactions                     | 837 | 22.9 Directory Systems                   | 865 |
| 22.4 Commit Protocols                             | 840 | 22.10 Summary                            | 870 |
| 22.5 Concurrency Control in Distributed Databases | 846 | Exercises                                | 873 |
| 22.6 Availability                                 | 854 | Bibliographical Notes                    | 876 |

**PART 8 ■ OTHER TOPICS****Chapter 23 Advanced Application Development**

- |                             |     |                       |     |
|-----------------------------|-----|-----------------------|-----|
| 23.1 Performance Tuning     | 881 | 23.5 Summary          | 900 |
| 23.2 Performance Benchmarks | 891 | Exercises             | 902 |
| 23.3 Standardization        | 895 | Bibliographical Notes | 903 |
| 23.4 Application Migration  | 899 |                       |     |

**Chapter 24 Advanced Data Types and New Applications**

- |                                  |     |                                      |     |
|----------------------------------|-----|--------------------------------------|-----|
| 24.1 Motivation                  | 905 | 24.5 Mobility and Personal Databases | 922 |
| 24.2 Time in Databases           | 906 | 24.6 Summary                         | 927 |
| 24.3 Spatial and Geographic Data | 908 | Exercises                            | 929 |
| 24.4 Multimedia Databases        | 919 | Bibliographical Notes                | 931 |

**Chapter 25 Advanced Transaction Processing**

- |                                      |     |  |     |
|--------------------------------------|-----|--|-----|
| 25.1 Transaction-Processing Monitors | 933 | 25.7 Transaction Management in<br>Multidatabases | 956 |
| 25.2 Transactional Workflows         | 938 | 25.8 Summary                                     | 959 |
| 25.3 E-Commerce                      | 944 | Exercises  | 962 |
| 25.4 Main-Memory Databases           | 947 | Bibliographical Notes                            | 964 |
| 25.5 Real-Time Transaction Systems   | 949 |  |     |
| 25.6 Long-Duration Transactions      | 950 |  |     |

**PART 9 ■ CASE STUDIES****Chapter 26 PostgreSQL**

- |  |     |   |     |
|--|-----|---|-----|
| 26.1 Introduction                            | 967 | 26.5 Storage and Indexing                 | 988 |
| 26.2 User Interfaces                         | 968 | 26.6 Query Processing and<br>Optimization | 991 |
| 26.3 SQL Variations and Extensions           | 971 | 26.7 System Architecture                  | 994 |
| 26.4 Transaction Management in<br>PostgreSQL | 979 | Bibliographical Notes                     | 995 |

## Chapter 27 Oracle

- 27.1 Database Design and Querying Tools 997
- 27.2 SQL Variations and Extensions 999
- 27.3 Storage and Indexing 1001
- 27.4 Query Processing and Optimization 1010
- 27.5 Concurrency Control and Recovery 1017
- 27.6 System Architecture 1019
- 27.7 Replication, Distribution, and External Data 1022
- 27.8 Database Administration Tools 1024
- 27.9 Data Mining 1025
- Bibliographical Notes 1026

## Chapter 28 IBM DB2 Universal Database

- 28.1 Overview 1027
- 28.2 Database-Design Tools 1029
- 28.3 SQL Variations and Extensions 1029
- 28.4 Storage and Indexing 1034
- 28.5 Multidimensional Clustering 1037
- 28.6 Query Processing and Optimization 1040
- 28.7 Materialized Query Tables 1045
- 28.8 Autonomic Features in DB2 1047
- 28.9 Tools and Utilities 1048
- 28.10 Concurrency Control and Recovery 1050
- 28.11 System Architecture 1052
- 28.12 Replication, Distribution and External Data 1053
- 28.13 Business Intelligence Features 1054
- Bibliographical Notes 1055

## Chapter 29 Microsoft SQL Server

- 29.1 Management, Design, and Querying Tools 1057
- 29.2 SQL Variations and Extensions 1062
- 29.3 Storage and Indexing 1066
- 29.4 Query Processing and Optimization 1069
- 29.5 Concurrency and Recovery 1074
- 29.6 System Architecture 1078
- 29.7 Data Access 1080
- 29.8 Distributed Heterogeneous Query Processing 1081
- 29.9 Replication 1082
- 29.10 Server Programming in .NET 1084
- 29.11 XML Support in SQL Server 2005 1089
- 29.12 SQL Server Service Broker 1094
- 29.13 Data Warehouse and Business Intelligence 1096
- Bibliographical Notes 1100

## PART 10 ■ APPENDICES

### Appendix A Network Model (contents online)

- A.1 Basic Concepts A1
- A.2 Data-Structure Diagrams A2
- A.3 The DBTG CODASYL Model A7
- A.4 DBTG Data-Retrieval Facility A13
- A.5 DBTG Update Facility A20
- A.6 DBTG Set-Processing Facility A22
- A.7 Mapping of Networks to Files A27
- A.8 Summary A31
- Exercises A32
- Bibliographical Notes A35



## **Appendix B Hierarchical Model (contents online)**

B.1 Basic Concepts	B1	B.6 Mapping of Hierarchies to Files	B22
B.2 Tree-Structure Diagrams	B2	B.7 The IMS Database System	B24
B.3 Data-Retrieval Facility	B13	B.8 Summary	B25
B.4 Update Facility	B18	Exercises	B26
B.5 Virtual Records	B21	Bibliographical Notes	B29

## **Appendix C Advanced Relational Database Design (contents online)**

C.1 Multivalued Dependencies	C1	C.4 Summary	C10
C.2 Join Dependencies	C5	Exercises	C10
C.3 Domain-Key Normal Form	C8	Bibliographical Notes	C11

**Bibliography 1101**

**Index 1129**