

Database System Concepts

Abraham Silberschatz
Henry F. Korth
S. Sudarshan

Sixth Edition

Mc
Graw
Hill

McGRAW-HILL INTERNATIONAL EDITION



Contents

Chapter 1 Introduction

- 1.1 Database-System Applications 1
- 1.2 Purpose of Database Systems 3
- 1.3 View of Data 6
- 1.4 Database Languages 9
- 1.5 Relational Databases 12
- 1.6 Database Design 15
- 1.7 Data Storage and Querying 20
- 1.8 Transaction Management 22
- 1.9 Database Architecture 23
- 1.10 Data Mining and Information Retrieval 25
- 1.11 Specialty Databases 26
- 1.12 Database Users and Administrators 27
- 1.13 History of Database Systems 29
- 1.14 Summary 31
- Exercises 33
- Bibliographical Notes 35

PART ONE ■ RELATIONAL DATABASES

Chapter 2 Introduction to the Relational Model

- 2.1 Structure of Relational Databases 39
- 2.2 Database Schema 42
- 2.3 Keys 45
- 2.4 Schema Diagrams 46
- 2.5 Relational Query Languages 47
- 2.6 Relational Operations 48
- 2.7 Summary 52
- Exercises 53
- Bibliographical Notes 55

Chapter 3 Introduction to SQL

- 3.1 Overview of the SQL Query Language 57
- 3.2 SQL Data Definition 58
- 3.3 Basic Structure of SQL Queries 63
- 3.4 Additional Basic Operations 74
- 3.5 Set Operations 79
- 3.6 Null Values 83
- 3.7 Aggregate Functions 84
- 3.8 Nested Subqueries 90
- 3.9 Modification of the Database 98
- 3.10 Summary 104
- Exercises 105
- Bibliographical Notes 112

Chapter 4 Intermediate SQL

- 4.1 Join Expressions 113
- 4.2 Views 120
- 4.3 Transactions 127
- 4.4 Integrity Constraints 128
- 4.5 SQL Data Types and Schemas 136
- 4.6 Authorization 143
- 4.7 Summary 150
 - Exercises 152
 - Bibliographical Notes 156

Chapter 5 Advanced SQL

- 5.1 Accessing SQL From a Programming Language 157
- 5.2 Functions and Procedures 173
- 5.3 Triggers 180
- 5.4 Recursive Queries** 187
- 5.5 Advanced Aggregation Features** 192
- 5.6 OLAP** 197
- 5.7 Summary 209
 - Exercises 211
 - Bibliographical Notes 216

Chapter 6 Formal Relational Query Languages

- 6.1 The Relational Algebra 217
- 6.2 The Tuple Relational Calculus 239
- 6.3 The Domain Relational Calculus 245
- 6.4 Summary 248
 - Exercises 249
 - Bibliographical Notes 254

PART TWO ■ DATABASE DESIGN

Chapter 7 Database Design and the E-R Model

- 7.1 Overview of the Design Process 259
- 7.2 The Entity-Relationship Model 262
- 7.3 Constraints 269
- 7.4 Removing Redundant Attributes in Entity Sets 272
- 7.5 Entity-Relationship Diagrams 274
- 7.6 Reduction to Relational Schemas 283
- 7.7 Entity-Relationship Design Issues 290
- 7.8 Extended E-R Features 295
- 7.9 Alternative Notations for Modeling Data 304
- 7.10 Other Aspects of Database Design 310
- 7.11 Summary 313
 - Exercises 315
 - Bibliographical Notes 321

Chapter 8 Relational Database Design

- | | |
|---|--|
| 8.1 Features of Good Relational Designs 323 | 8.6 Decomposition Using Multivalued Dependencies 355 |
| 8.2 Atomic Domains and First Normal Form 327 | 8.7 More Normal Forms 360 |
| 8.3 Decomposition Using Functional Dependencies 329 | 8.8 Database-Design Process 361 |
| 8.4 Functional-Dependency Theory 338 | 8.9 Modeling Temporal Data 364 |
| 8.5 Algorithms for Decomposition 348 | 8.10 Summary 367 |
| | Exercises 368 |
| | Bibliographical Notes 374 |

Chapter 9 Application Design and Development

- | | |
|--|---|
| 9.1 Application Programs and User Interfaces 375 | 9.6 Application Performance 400 |
| 9.2 Web Fundamentals 377 | 9.7 Application Security 402 |
| 9.3 Servlets and JSP 383 | 9.8 Encryption and Its Applications 411 |
| 9.4 Application Architectures 391 | 9.9 Summary 417 |
| 9.5 Rapid Application Development 396 | Exercises 419 |
| | Bibliographical Notes 426 |

PART THREE ■ DATA STORAGE AND QUERYING

Chapter 10 Storage and File Structure

- | | |
|---|---|
| 10.1 Overview of Physical Storage Media 429 | 10.6 Organization of Records in Files 457 |
| 10.2 Magnetic Disk and Flash Storage 432 | 10.7 Data-Dictionary Storage 462 |
| 10.3 RAID 441 | 10.8 Database Buffer 464 |
| 10.4 Tertiary Storage 449 | 10.9 Summary 468 |
| 10.5 File Organization 451 | Exercises 470 |
| | Bibliographical Notes 473 |

Chapter 11 Indexing and Hashing

- | | |
|---|---|
| 11.1 Basic Concepts 475 | 11.8 Comparison of Ordered Indexing and Hashing 523 |
| 11.2 Ordered Indices 476 | 11.9 Bitmap Indices 524 |
| 11.3 B ⁺ -Tree Index Files 485 | 11.10 Index Definition in SQL 528 |
| 11.4 B ⁺ -Tree Extensions 500 | 11.11 Summary 529 |
| 11.5 Multiple-Key Access 506 | Exercises 532 |
| 11.6 Static Hashing 509 | Bibliographical Notes 536 |
| 11.7 Dynamic Hashing 515 | |

Chapter 12 Query Processing

- 12.1 Overview 537
- 12.2 Measures of Query Cost 540
- 12.3 Selection Operation 541
- 12.4 Sorting 546
- 12.5 Join Operation 549
- 12.6 Other Operations 563
- 12.7 Evaluation of Expressions 567
- 12.8 Summary 572
- Exercises 574
- Bibliographical Notes 577

Chapter 13 Query Optimization

- 13.1 Overview 579
- 13.2 Transformation of Relational Expressions 582
- 13.3 Estimating Statistics of Expression Results 590
- 13.4 Choice of Evaluation Plans 598
- 13.5 Materialized Views** 607
- 13.6 Advanced Topics in Query Optimization** 612
- 13.7 Summary 615
- Exercises 617
- Bibliographical Notes 622

PART FOUR ■ TRANSACTION MANAGEMENT**Chapter 14 Transactions**

- 14.1 Transaction Concept 627
- 14.2 A Simple Transaction Model 629
- 14.3 Storage Structure 632
- 14.4 Transaction Atomicity and Durability 633
- 14.5 Transaction Isolation 635
- 14.6 Serializability 641
- 14.7 Transaction Isolation and Atomicity 646
- 14.8 Transaction Isolation Levels 648
- 14.9 Implementation of Isolation Levels 650
- 14.10 Transactions as SQL Statements 653
- 14.11 Summary 655
- Exercises 657
- Bibliographical Notes 660

Chapter 15 Concurrency Control

- 15.1 Lock-Based Protocols 661
- 15.2 Deadlock Handling 674
- 15.3 Multiple Granularity 679
- 15.4 Timestamp-Based Protocols 682
- 15.5 Validation-Based Protocols 686
- 15.6 Multiversion Schemes 689
- 15.7 Snapshot Isolation 692
- 15.8 Insert Operations, Delete Operations, and Predicate Reads 697
- 15.9 Weak Levels of Consistency in Practice 701
- 15.10 Concurrency in Index Structures** 704
- 15.11 Summary 708
- Exercises 712
- Bibliographical Notes 718

Chapter 16 Recovery System

- | | |
|---|---|
| 16.1 Failure Classification 721 | 16.7 Early Lock Release and Logical Undo Operations 744 |
| 16.2 Storage 722 | 16.8 ARIES** 750 |
| 16.3 Recovery and Atomicity 726 | 16.9 Remote Backup Systems 756 |
| 16.4 Recovery Algorithm 735 | 16.10 Summary 759 |
| 16.5 Buffer Management 738 | Exercises 762 |
| 16.6 Failure with Loss of Nonvolatile Storage 743 | Bibliographical Notes 766 |

PART FIVE ■ SYSTEM ARCHITECTURE**Chapter 17 Database-System Architectures**

- | | |
|--|---------------------------|
| 17.1 Centralized and Client-Server Architectures 769 | 17.5 Network Types 788 |
| 17.2 Server System Architectures 772 | 17.6 Summary 791 |
| 17.3 Parallel Systems 777 | Exercises 793 |
| 17.4 Distributed Systems 784 | Bibliographical Notes 794 |

Chapter 18 Parallel Databases

- | | |
|-------------------------------------|--|
| 18.1 Introduction 797 | 18.8 Design of Parallel Systems 815 |
| 18.2 I/O Parallelism 798 | 18.9 Parallelism on Multicore Processors 817 |
| 18.3 Interquery Parallelism 802 | 18.10 Summary 819 |
| 18.4 Intraquery Parallelism 803 | Exercises 821 |
| 18.5 Intraoperation Parallelism 804 | Bibliographical Notes 824 |
| 18.6 Interoperation Parallelism 813 | |
| 18.7 Query Optimization 814 | |

Chapter 19 Distributed Databases

- | | |
|---|--|
| 19.1 Homogeneous and Heterogeneous Databases 825 | 19.7 Distributed Query Processing 854 |
| 19.2 Distributed Data Storage 826 | 19.8 Heterogeneous Distributed Databases 857 |
| 19.3 Distributed Transactions 830 | 19.9 Cloud-Based Databases 861 |
| 19.4 Commit Protocols 832 | 19.10 Directory Systems 870 |
| 19.5 Concurrency Control in Distributed Databases 839 | 19.11 Summary 875 |
| 19.6 Availability 847 | Exercises 879 |
| | Bibliographical Notes 883 |

PART SIX ■ DATA WAREHOUSING, DATA MINING, AND INFORMATION RETRIEVAL

Chapter 20 Data Warehousing and Mining

- | | | | |
|----------------------------------|-----|---------------------------------|-----|
| 20.1 Decision-Support Systems | 887 | 20.7 Clustering | 907 |
| 20.2 Data Warehousing | 889 | 20.8 Other Forms of Data Mining | 908 |
| 20.3 Data Mining | 893 | 20.9 Summary | 909 |
| 20.4 Classification | 894 | Exercises | 911 |
| 20.5 Association Rules | 904 | Bibliographical Notes | 914 |
| 20.6 Other Types of Associations | 906 | | |

Chapter 21 Information Retrieval

- | | | | |
|---|-----|---|-----|
| 21.1 Overview | 915 | 21.7 Crawling and Indexing the Web | 930 |
| 21.2 Relevance Ranking Using Terms | 917 | 21.8 Information Retrieval: Beyond Ranking of Pages | 931 |
| 21.3 Relevance Using Hyperlinks | 920 | 21.9 Directories and Categories | 935 |
| 21.4 Synonyms, Homonyms, and Ontologies | 925 | 21.10 Summary | 937 |
| 21.5 Indexing of Documents | 927 | Exercises | 939 |
| 21.6 Measuring Retrieval Effectiveness | 929 | Bibliographical Notes | 941 |

PART SEVEN ■ SPECIALTY DATABASES

Chapter 22 Object-Based Databases

- | | | | |
|---|-----|--|-----|
| 22.1 Overview | 945 | 22.8 Persistent Programming Languages | 964 |
| 22.2 Complex Data Types | 946 | 22.9 Object-Relational Mapping | 973 |
| 22.3 Structured Types and Inheritance in SQL | 949 | 22.10 Object-Oriented versus Object-Relational | 973 |
| 22.4 Table Inheritance | 954 | 22.11 Summary | 975 |
| 22.5 Array and Multiset Types in SQL | 956 | Exercises | 976 |
| 22.6 Object-Identity and Reference Types in SQL | 961 | Bibliographical Notes | 980 |
| 22.7 Implementing O-R Features | 963 | | |

Chapter 23 XML

- | | | | |
|--|------|--------------------------|------|
| 23.1 Motivation | 981 | 23.6 Storage of XML Data | 1009 |
| 23.2 Structure of XML Data | 986 | 23.7 XML Applications | 1016 |
| 23.3 XML Document Schema | 990 | 23.8 Summary | 1019 |
| 23.4 Querying and Transformation | 998 | Exercises | 1021 |
| 23.5 Application Program Interfaces to XML | 1008 | Bibliographical Notes | 1024 |

PART EIGHT ■ ADVANCED TOPICS

Chapter 24 Advanced Application Development

- | | | | |
|--|------|-----------------------|------|
| 24.1 Performance Tuning | 1029 | 24.4 Standardization | 1051 |
| 24.2 Performance Benchmarks | 1045 | 24.5 Summary | 1056 |
| 24.3 Other Issues in Application Development | 1048 | Exercises | 1057 |
| | | Bibliographical Notes | 1059 |

Chapter 25 Spatial and Temporal Data and Mobility

- | | | | |
|----------------------------------|------|--------------------------------------|------|
| 25.1 Motivation | 1061 | 25.5 Mobility and Personal Databases | 1079 |
| 25.2 Time in Databases | 1062 | 25.6 Summary | 1085 |
| 25.3 Spatial and Geographic Data | 1064 | Exercises | 1087 |
| 25.4 Multimedia Databases | 1076 | Bibliographical Notes | 1089 |

Chapter 26 Advanced Transaction Processing

- | | | | |
|---------------------------------------|------|---------------------------------|------|
| 26.1 Transaction-Processing Monitors | 1091 | 26.6 Long-Duration Transactions | 1109 |
| 26.2 Transactional Workflows | 1096 | 26.7 Summary | 1115 |
| 26.3 E-Commerce | 1102 | Exercises | 1117 |
| 26.4 Main-Memory Databases | 1105 | Bibliographical Notes | 1119 |
| 26.5 Real-Time Transaction Systems | 1108 | | |

PART NINE ■ CASE STUDIES

Chapter 27 PostgreSQL

- | | | | |
|---|------|--|------|
| 27.1 Introduction | 1123 | 27.5 Storage and Indexing | 1146 |
| 27.2 User Interfaces | 1124 | 27.6 Query Processing and Optimization | 1151 |
| 27.3 SQL Variations and Extensions | 1126 | 27.7 System Architecture | 1154 |
| 27.4 Transaction Management in PostgreSQL | 1137 | Bibliographical Notes | 1155 |

Chapter 28 Oracle

- | | | | |
|---|------|---|------|
| 28.1 Database Design and Querying Tools | 1157 | 28.6 System Architecture | 1183 |
| 28.2 SQL Variations and Extensions | 1158 | 28.7 Replication, Distribution, and External Data | 1188 |
| 28.3 Storage and Indexing | 1162 | 28.8 Database Administration Tools | 1189 |
| 28.4 Query Processing and Optimization | 1172 | 28.9 Data Mining | 1191 |
| 28.5 Concurrency Control and Recovery | 1180 | Bibliographical Notes | 1191 |

Chapter 29 IBM DB2 Universal Database

- 29.1 Overview 1193
- 29.2 Database-Design Tools 1194
- 29.3 SQL Variations and Extensions 1195
- 29.4 Storage and Indexing 1200
- 29.5 Multidimensional Clustering 1203
- 29.6 Query Processing and Optimization 1207
- 29.7 Materialized Query Tables 1212
- 29.8 Autonomic Features in DB2 1214
- 29.9 Tools and Utilities 1215
- 29.10 Concurrency Control and Recovery 1217
- 29.11 System Architecture 1219
- 29.12 Replication, Distribution, and External Data 1220
- 29.13 Business Intelligence Features 1221
- Bibliographical Notes 1222

Chapter 30 Microsoft SQL Server

- 30.1 Management, Design, and Querying Tools 1223
- 30.2 SQL Variations and Extensions 1228
- 30.3 Storage and Indexing 1233
- 30.4 Query Processing and Optimization 1236
- 30.5 Concurrency and Recovery 1241
- 30.6 System Architecture 1246
- 30.7 Data Access 1248
- 30.8 Distributed Heterogeneous Query Processing 1250
- 30.9 Replication 1251
- 30.10 Server Programming in .NET 1253
- 30.11 XML Support 1258
- 30.12 SQL Server Service Broker 1261
- 30.13 Business Intelligence 1263
- Bibliographical Notes 1267

PART TEN ■ APPENDICES

Appendix A Detailed University Schema

- A.1 Full Schema 1271
- A.2 DDL 1272
- A.3 Sample Data 1276

Appendix B Advanced Relational Design (contents online)

- B.1 Multivalued Dependencies B1
- B.3 Domain-Key Normal Form B8
- B.4 Summary B10
- Exercises B10
- Bibliographical Notes B12

Appendix C Other Relational Query Languages (contents online)

- C.1 Query-by-Example C1
- C.2 Microsoft Access C9
- C.3 Datalog C11
- C.4 Summary C25
- Exercises C26
- Bibliographical Notes C30

Appendix D Network Model (contents online)

D.1 Basic Concepts	D1	D.6 DBTG Set-Processing Facility	D22
D.2 Data-Structure Diagrams	D2	D.7 Mapping of Networks to Files	D27
D.3 The DBTG CODASYL Model	D7	D.8 Summary	D31
D.4 DBTG Data-Retrieval Facility	D13	Exercises	D32
D.5 DBTG Update Facility	D20	Bibliographical Notes	D35

Appendix E Hierarchical Model (contents online)

E.1 Basic Concepts	E1	E.6 Mapping of Hierarchies to Files	E22
E.2 Tree-Structure Diagrams	E2	E.7 The IMS Database System	E24
E.3 Data-Retrieval Facility	E13	E.8 Summary	E25
E.4 Update Facility	E17	Exercises	E26
E.5 Virtual Records	E20	Bibliographical Notes	E29

Bibliography 1283

Index 1315