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

Chapter 5 Advanced SQL

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

Chapter 6 Formal Relational Query Languages

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

PART TWO ■ DATABASE DESIGN**Chapter 7 Database Design and the E-R Model**

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

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 640
- 14.7 Transaction Isolation and Atomicity 647
- 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 | 29.9 Tools and Utilities | 1215 |
| 29.2 Database-Design Tools | 1194 | 29.10 Concurrency Control and Recovery | 1217 |
| 29.3 SQL Variations and Extensions | 1195 | 29.11 System Architecture | 1219 |
| 29.4 Storage and Indexing | 1200 | 29.12 Replication, Distribution, and External Data | 1220 |
| 29.5 Multidimensional Clustering | 1203 | 29.13 Business Intelligence Features | 1221 |
| 29.6 Query Processing and Optimization | 1207 | Bibliographical Notes | 1222 |
| 29.7 Materialized Query Tables | 1212 | | |
| 29.8 Autonomic Features in DB2 | 1214 | | |

Chapter 30 Microsoft SQL Server

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

PART TEN ■ APPENDICES**Appendix A Detailed University Schema**

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

Appendix B Advanced Relational Design (contents online)

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

Appendix C Other Relational Query Languages (contents online)

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