#### INTERNATIONAL EDITION

Fundamentals of

## DATABASE SYSTEMS

FOURTH EDITION

**ELMASRI** NAVATHE

#### PART 1 INTRODUCTION AND CONCEPTUAL MODELING

CHAPTER 1 Databases and Database Ligars

C	ien i Databases and Database Osers	
1.1	Introduction 4	
1.2	An Example 6	
1.3	Characteristics of the Database Approach	8
1.4	Actors on the Scene 12	
1.5	Workers behind the Scene 14	
1.6	Advantages of Using the DBMS Approach	15
1.7	A Brief History of Database Applications	20
1.8	When Not to Use a DBMS 23	
1.9	Summary 23	
	Review Questions 23	
	Exercises 24	
	Selected Bibliography 24	

CHA	PTER 2 Database System Concepts and
	Architecture 25
2.1	Data Models, Schemas, and Instances 26
2.2	Three-Schema Architecture and Data Independence 29
2.3	Database Languages and Interfaces 32
2.4	
2.5	Centralized and Client/Server Architectures for DBMSs 38
2.6	Classification of Database Management Systems 43
	Summary 45
	Review Questions 46
	Exercises 46
	Selected Bibliography 47
CHA	PTER 3 Data Modeling Using the Entity-Relationship
	Model 49
3.1	Using High-Level Conceptual Data Models for Database
	Design 50
3.2	1 11
	Entity Types, Entity Sets, Attributes, and Keys 53
3.4	
	Constraints 61
3.5	/ /L
3.6	
3.7	
3.8	
3.9	,
	Review Questions 78
	Exercises 78
	Selected Bibliography 83
СНА	PTER 4 Enhanced Entity-Relationship and UML
	Modeling 85
4.1	Subclasses, Superclasses, and Inheritance 86
4.2	Specialization and Generalization 88
4.3	•
	Generalization 91
4.4	Modeling of UNION Types Using Categories 98
4.5	An Example UNIVERSITY EER Schema and Formal Definitions
	for the EER Model 101

4.6	Representing Specialization/Generalization and Inheritance in UML Class Diagrams 104
4.7	Relationship Types of Degree Higher Than Two 105
4.0	Data Abstraction, Knowledge Representation, and Ontology
4.0	Concepts 110
4.9	,
	Review Questions 116
	Exercises 117
	Selected Bibliography 121
	2 RELATIONAL MODEL: CONCEPTS, CONSTRAINTS,
LANG	GUAGES, DESIGN, AND PROGRAMMING
СНА	PTER 5 The Relational Data Model and
	Relational Database Constraints 125
5.1	Relational Model Concepts 126
5.2	Relational Model Constraints and Relational Database
	Schemas 132
5.3	Update Operations and Dealing with Constraint Violations 140
	Summary 143
	Review Questions 144
	Exercises 144
	Selected Bibliography 147
CHA	PTER 6 The Relational Algebra and Relational
	Calculus 149
	Unary Relational Operations: SELECT and PROJECT 151
6.2	Relational Algebra Operations from Set Theory 155
6.3	Binary Relational Operations: JOIN and DIVISION 158
	Additional Relational Operations 165
6.5	Examples of Queries in Relational Algebra 171
6.6	The Tuple Relational Calculus 173
6.7	The Domain Relational Calculus 181
6.8	Summary 184
	Review Questions 185
	Exercises 186
	Selected Bibliography 189

CHAPTER 7 Relational Database Design by	
<u></u> .	ER- and EER-to-Relational Mapping 191
7.1	Relational Database Design Using ER-to-Relational
7.3	Mapping 192
	Mapping EER Model Constructs to Relations 199
1.3	Summary 203
	Review Questions 204 Exercises 204
	Selected Bibliography 205
	Selected Dibliographty 203
CHA	PTER 8 SQL-99: Schema Definition,
	Basic Constraints, and Queries 207
8.1	71
8.2	1 , 0
8.3	•
	Basic Queries in SQL 218
8.5	
8.6	· · · · · · · · · · · · · · · · · · ·
8.8	Additional Features of SQL 248 Summary 249
0.0	Review Questions 251
	Exercises 251
	Selected Bibliography 252
	Colocted Distriction, 252
CHA	PTER 9 More SQL: Assertions, Views, and Programming
	Techniques 255
	Specifying General Constraints as Assertions 256
	Views (Virtual Tables) in SQL 257
9.3	
	Embedded SQL, Dynamic SQL, and SQLJ 264
9.5	
0.6	JDBC 275
9.7	Database Stored Procedures and SQL/PSM 284 Summary 287
7.1	Review Questions 287
	Exercises 287
	Selected Bibliography 289

#### PART 3 DATABASE DESIGN THEORY AND METHODOLOGY

CHA	PTER 10 Functional Dependencies and
	Normalization for Relational Databases 293
10.1	Informal Design Guidelines for Relation Schemas 295
10.2	Functional Dependencies 304
10.3	Normal Forms Based on Primary Keys 312
10.4	General Definitions of Second and Third Normal Forms 320
10.5	Boyce-Codd Normal Form 324
10.6	Summary 326
	Review Questions 327
	Exercises 328
	Selected Bibliography 331
CHA	PTER 11 Relational Database Design
	Algorithms and Further Dependencies 333
11.1	Properties of Relational Decompositions 334
11.2	Algorithms for Relational Database Schema Design 340
11.3	Multivalued Dependencies and Fourth Normal Form 347
	Join Dependencies and Fifth Normal Form 353
	Inclusion Dependencies 354
	Other Dependencies and Normal Forms 355
11.7	,
	Review Questions 358
	Exercises 358
	Selected Bibliography 360
СНА	PTER 12 Practical Database Design Methodology
	and Use of UML Diagrams 361
12.1	The Role of Information Systems in Organizations 362
	The Database Design and Implementation Process 366
12.3	Use of UML Diagrams as an Aid to Database Design
	Specification 385
	Rational Rose, A UML Based Design Tool 395
	Automated Database Design Tools 402
12.6	Summary 404
	Review Questions 405
	Selected Bibliography 406

### PART 4 DATA STORAGE, INDEXING, QUERY PROCESSING, AND PHYSICAL DESIGN

## CHAPTER 13 Disk Storage, Basic File Structures, and Hashing 411

	riasining 711
13.1	Introduction 412
13.2	Secondary Storage Devices 415
13.3	Buffering of Blocks 421
13.4	Placing File Records on Disk 422
13.5	Operations on Files 427
13.6	Files of Unordered Records (Heap Files) 430
13.7	Files of Ordered Records (Sorted Files) 431
13.8	Hashing Techniques 434
13.9	Other Primary File Organizations 442
13.10	Parallelizing Disk Access Using RAID Technology 443
13.11	Storage Area Networks 447
13.12	Summary 449
	Review Questions 450
	Exercises 451
	Selected Bibliography 454

### **CHAPTER 14 Indexing Structures for Files**14.1 Types of Single-Level Ordered Indexes 456

14.2	Multilevel Indexes 464
14.3	Dynamic Multilevel Indexes Using B-Trees and B+-Trees
14.4	Indexes on Multiple Keys 483
14.5	Other Types of Indexes 485
14.6	Summary 486
	Review Questions 487
	Exercises 488
	Selected Bibliography 490

469

# CHAPTER 15 Algorithms for Query Processing and Optimization 493 15.1 Translating SQL Queries into Relational Algebra

- 15.1 Translating SQL Queries into Relational Algebra 495
  15.2 Algorithms for External Sorting 496
  15.3 Algorithms for SELECT and IOIN Operations 498
- 15.3 Algorithms for SELECT and JOIN Operations15.4 Algorithms for PROJECT and SET Operations508

15.6 15.7 15.8 15.9 15.10	Implementing Aggregate Operations and Outer Joins 509 Combining Operations Using Pipelining 511 Using Heuristics in Query Optimization 512 Using Selectivity and Cost Estimates in Query Optimization 523 Overview of Query Optimization in ORACLE 532 Semantic Query Optimization 533 Summary 534 Review Questions 534 Exercises 535 Selected Bibliography 536
CHA	PTER 16 Practical Database Design and Tuning 537
	Physical Database Design in Relational Databases 537
	An Overview of Database Tuning in Relational Systems 541
	Summary 547
	Review Questions 547
	Selected Bibliography 548
PART	5 TRANSACTION PROCESSING CONCEPTS
СНА	PTER 17 Introduction to Transaction
	Processing Concepts and Theory 551
	Introduction to Transaction Processing 552
17.2	Transaction and System Concepts 559
17.3	Desirable Properties of Transactions 562
17.4 17.5	Characterizing Schedules Based on Recoverability 563 Characterizing Schedules Based on Serializability 566
17.6	Transaction Support in SQL 576
17.7	• •
	Review Questions 579
	Exercises 580
	Selected Bibliography 581
CHA	PTER 18 Concurrency Control Techniques 583
18.1	Two-Phase Locking Techniques for Concurrency Control 584
18.2	Concurrency Control Based on Timestamp Ordering 594
18.3	Multiversion Concurrency Control Techniques 596
18.4	Validation (Optimistic) Concurrency Control Techniques 599

18.5 18.6 18.7 18.8	Granularity of Data Items and Multiple Granularity Locking Using Locks for Concurrency Control in Indexes 605 Other Concurrency Control Issues 606 Summary 607 Review Questions 608 Exercises 609
CHAI	Selected Bibliography 609  PTER 19 Database Recovery Techniques 611
19.1	• •
19.2 19.3 19.4	Recovery Techniques Based on Deferred Update 618 Recovery Techniques Based on Immediate Update 622 Shadow Paging 624
	The ARIES Recovery Algorithm 625
19.7	Recovery in Multidatabase Systems 629 Database Backup and Recovery from Catastrophic Failures 630 Summary 631 Review Questions 632 Exercises 633 Selected Bibliography 635
PART	6 OBJECT AND OBJECT-RELATIONAL DATABASES
CHA	PTER 20 Concepts for Object Databases 639
	Overview of Object-Oriented Concepts 641
20.3 20.4 20.5	Review Questions 663 Exercises 664
	Selected Bibliography 664
СНА	PTER 21 Object Database Standards, Languages, and Design 665
21.1	Overview of the Object Model of ODMG 666

CHAF	CHAPTER 24 Enhanced Data Models for Advanced	
	Applications 755	
24.1	Active Database Concepts and Triggers 757	
	Temporal Database Concepts 767	
	Multimedia Databases 780	
24.4	Introduction to Deductive Databases 784	
24.5	Summary 797	
	Review Questions 797	
	Exercises 798	
	Selected Bibliography 801	
CHAI	PTER 25 Distributed Databases and	
C	Client–Server Architectures 803	
25.1	Distributed Database Concepts 804	
25.2		
LJ.L	Allocation Techniques for Distributed Database Design 810	
25 3	Types of Distributed Database Systems 815	
	Query Processing in Distributed Databases 818	
	Overview of Concurrency Control and Recovery in Distributed	
23.3	Databases 824	
25.6	An Overview of 3-Tier Client-Server Architecture 827	
	Distributed Databases in Oracle 830	
	Summary 832	
	Review Questions 833	
	Exercises 834	
	Selected Bibliography 835	
PART	8 EMERGING TECHNOLOGIES	
CHA	PTER 26 XML and Internet Databases 841	
26.1	Structured, Semistructured, and Unstructured Data 842	
26.2	XML Hierarchical (Tree) Data Model 846	
26.3	XML Documents, DTD, and XML Schema 848	
26.4	XML Documents and Databases 855	
26.5	XML Querying 862	
26.6	Summary 865	
	Review Questions 865	
	Exercises 866	
	Selected Bibliography 866	

CHAI	PTER 27 Data Mining Concepts 867
27.1	Overview of Data Mining Technology 868
	Association Rules 871
27.3	Classification 882
27.4	Clustering 885
27.5	Approaches to Other Data Mining Problems 888
	Applications of Data Mining 891
	Commercial Data Mining Tools 891
27.8	Summary 894
	Review Questions 894
	Exercises 895
	Selected Bibliography 896
CHAI	PTER 28 Overview of Data Warehousing and
	OLAP 899
28.1	Introduction, Definitions, and Terminology 900
28.2	Characteristics of Data Warehouses 901
28.3	Data Modeling for Data Warehouses 902
28.4	Building a Data Warehouse 907
28.5	Typical Functionality of a Data Warehouse 910
28.6	Data Warehouse Versus Views 911
28.7	Problems and Open Issues in Data Warehouses 912
28.8	,
	Review Questions 914
	Selected Bibliography 914
CHAI	PTER 29 Emerging Database Technologies and
	Applications 915
29.1	Mobile Databases 916
29.2	Multimedia Databases 923
29.3	Geographic Information Systems 930

29.4 Genome Data Management

APPENDIX A	Alternative Diagrammatic Notations	947
APPENDIX B	Database Design and Application Implementation Case Study—located on	the w

APPENDIX C Parameters of Disks 951

APPENDIX D Overview of the QBE Language 955

APPENDIX E Hierarchical Data Model—located on the web

APPENDIX F Network Data Model—located on the web

Selected Bibliography 963

Index 1009