

PREFACE xxii  
Part I BASICS 1

1 INTRODUCTION TO DATABASE SYSTEMS 3

- 1.1 Overview 4
- 1.2 A Historical Perspective 5
- 1.3 File Systems versus a DBMS 7
- 1.4 Advantages of a DBMS 8
- 1.5 Describing and Storing Data in a DBMS 9
  - 1.5.1 The Relational Model 10
  - 1.5.2 Levels of Abstraction in a DBMS 11
  - 1.5.3 Data Independence 14
- 1.6 Queries in a DBMS 15
- 1.7 Transaction Management 15
  - 1.7.1 Concurrent Execution of Transactions 16
  - 1.7.2 Incomplete Transactions and System Crashes 17
  - 1.7.3 Points to Note 18
- 1.8 Structure of a DBMS 18
- 1.9 People Who Deal with Databases 20
- 1.10 Points to Review 21

2 THE ENTITY-RELATIONSHIP MODEL 24

- 2.1 Overview of Database Design 24
  - 2.1.1 Beyond the ER Model 24
- 2.2 Entities, Attributes, and Entity Sets 26
- 2.3 Relationships and Relationship Sets 27
- 2.4 Additional Features of the ER Model 30
  - 2.4.1 Key Constraints 30
  - 2.4.2 Participation Constraints 32
  - 2.4.3 Weak Entities 33
  - 2.4.4 Class Hierarchies 35
  - 2.4.5 Aggregation 37
- 2.5 Conceptual Database Design With the ER Model 38
  - 2.5.1 Entity versus Attribute 39
  - 2.5.2 Entity versus Relationship 40
  - 2.5.3 Binary versus Ternary Relationships \* 41
  - 2.5.4 Aggregation versus Ternary relationships \* 43
- 2.6 Conceptual Design for Large Enterprises \* 44
- 2.7 Points to Review

2 THE RELATIONAL MODEL 51

- 3.1 Introduction to the Relational Model 52
  - 3.1.1 Creating and Modifying Relations Using SQL-92 55
- 3.2 Integrity Constraints over Relations 56
  - 3.2.1 Key Constraints 57
  - 3.2.2 Foreign Key Constraints 59
  - 3.2.3 General Constraints 61
- 3.3 Enforcing Integrity Constraints 62
- 3.4 Querying Relational Data 64
- 3.5 Logical Database Design: ER to Relational 66
  - 3.5.1 Entity Sets to Tables 67
  - 3.5.2 Relationship Sets (without Constraints) to Tables 67
  - 3.5.3 Translating Relationship Sets with Key Constraints 69
  - 3.5.4 Translating Relationship Sets with Participation Constraints 71

- 3.5.5 Translating Weak Entity Sets 73
- 3.5.6 Translating Class Hierarchies 74
- 3.5.7 Translating ER Diagrams with Aggregation 75
- 3.5.8 ER to Relational: Additional Examples \* 76
- 3.6 Introduction to Views 78
- 3.6.1 Views, Data Independence, Security 79
- 3.6.2 Updates on Views 79
- 3.7 Destroying/Altering Tables and Views 82
- 3.8 Points to Review 83

## Part II 89

### 4 RELATIONAL ALGEBRA AND CALCULUS 91

- 4.1 Preliminaries 91
- 4.2 Relational Algebra 91
  - 4.2.1 Selection and Projection 92
  - 4.2.2 Set Operations 93
  - 4.2.3 Renaming 94
  - 4.2.4 Joins 96
  - 4.2.5 Division 97
  - 4.2.6 More Examples of Relational Algebra Queries 100
- 4.3 Relational Calculus 106
  - 4.3.1 Tuple Relational Calculus 107
  - 4.3.2 Domain Relational Calculus 111
- 4.4 Expressive Power of Algebra and Calculus \* 114
- 4.5 Points to Review 115

### 5 SQL: QUERIES, PROGRAMMING, TRIGGERS 119

- 5.1 About the Examples 121
- 5.2 The Form of a Basic SQL Queries 121
  - 5.2.1 Examples of Basic SQL Queries 126
  - 5.2.2 Expressions and Strings in the SELECT Command 127
- 5.3 UNION, INTERSECT, and EXCEPT 129
- 5.4 NESTED Queries 132
  - 5.4.1 Introduction to Nested Queries 132
  - 5.4.2 Correlated Nested Queries 134
  - 5.4.3 Set-Comparison Operators 135
  - 5.4.4 More Examples of Nested Queries 136
- 5.5 Aggregate Operators 138
  - 5.5.1 The GROUP BY and HAVING Clauses 140
  - 5.5.2 More Examples of Aggregate Queries 143
- 5.6 Null Values \*
- 5.6.1 Comparisons Using Null Values 147
- 5.6.2 Logical Connectives AND, OR, and NOT 148
- 5.6.3 Impact on AQL Constructs 148
- 5.6.4 Outer Joins 149
- 5.6.5 Disallowing Null Values 149
- 5.7 Embedded SQL \* 150
  - 5.7.1 Declaring Variables and Exceptions 151
  - 5.7.2 Embedding SQL Statements 152
- 5.8 Cursors \* 153
  - 5.8.1 Basic Cursor Definition and Usage 153
  - 5.8.2 Properties of Cursors 155
- 5.9 Dynamic SQL \* 156

5.10 ODBC and JDBC *	157
5.10.1 Architecture	158
5.10.2 An Example Using JDBC	159
5.11 Complex Integrity Constraints in SQL-92 *	161
5.11.1 Constraints over a Single Table	161
5.11.2 Domain Constraints	162
5.11.3 Assertions: ICs over Several Tables	163
5.12 Triggers and Active Databases	164
5.12.1 Examples of Triggers in SQL	165
5.13 Designing Active Databases	166
5.13.1 Why Triggers Can Be Hard to Understand	167
5.13.2 Constraints versus Triggers	167
5.13.3 Other Uses of Triggers	168
5.14 Points to Review	168
 6 QUERY-BY-EXAMPLE (QBE)	
6.1 Introduction	177
6.2 Basic QBE Queries	177
6.2.1 Other Features: Duplicates, Ordering Answers	178
6.3 Queries over Multiple Relations	179
6.4 Negation in the Relation-Name Column	180
6.5 Aggregates	181
6.6 The Conditions Box	181
6.6.1 And/Or Queries	183
6.7 Unnamed Columns	185
6.8 Updates	185
6.8.1 Restrictions on Update Commands	187
6.9 Division and Relational Completeness *	187
6.10 Points to Review	189
 Part III DATA STORAGE AND INDEXING	193
 7 STORING DATA: DISKS AND FILES	195
7.1 The Memory Hierarchy	196
7.1.1 Magnetic Disks	197
7.1.2 Performance Implications of Disk Structure	199
7.2 RAID	
7.2.1 Data Striping	200
7.2.2 Redundancy	201
7.2.3 Levels of Redundancy	203
7.2.4 Choice of RAID Levels	206
7.3 Disk Space Management	207
7.3.1 Keeping Track of Free Blocks	207
7.3.2 Using OS File Systems to Manage Disk Space	207
7.4 Buffer Manager	208
7.4.1 Buffer Replacement Policies	211
7.4.2 Buffer Management in DBMS versus OS	212
7.5 Files and Indexes	214
7.5.1 Heap Files	214
7.5.2 Introduction to Indexes	216
7.6 Pages Formats *	218
7.6.1 Fixed-Length Records	218
7.6.2 Variable-Length Records	219
7.7 Record Formats *	221

7.7.1 Fixed-Length Records	222
7.7.2 Variable-Length Records	222
7.8 Points to Review	224
8 FILE ORGANIZATIONS AND INDEXES	230
8.1 Cost Model	231
8.2 Comparison of Three File Organizations	232
8.2.1 Heap Files	232
8.2.2 Sorted Files	233
8.2.3 Hashed Files	235
8.2.4 Choosing a File Organization	236
8.3 Overview of Indexes	237
8.3.1 Alternatives for Data Entries in an Index	238
8.4 Properties of Indexes	239
8.4.1 Clustered versus Unclustered Indexes	239
8.4.2 Dense versus Sparse Indexes	241
8.4.3 Primary and Secondary indexes	242
8.4.4 Indexes Using Composite Search keys	243
8.5 Index Specification in SQL-92	244
8.6 Points to Review	244
9 TREE-STRUCTURED INDEXING	247
9.1 Indexed Sequential Access Method (ISAM)	248
9.2 B+ Trees: A Dynamic Index Structure	253
9.3 Format of a Node	254
9.4 Search	255
9.5 Insert	257
9.6 Delete *	260
9.7 Duplicates *	265
9.8 B+ Trees in Practice *	266
9.8.1 Key Compression	266
9.8.2 Bulk-loading a B+ Tree	268
9.8.3 The Order Concept	271
9.8.4 The Effect of Inserts and Deletes on Rids	272
9.9 Points to Review	272
10 HASH-BASED INDEXING	278
10.1 Static Hashing	278
10.1.1 Notation and Conventions	280
10.2 Extendible Hashing *	280
10.3 Linear Hashing *	280
10.4 Extendible Hashing versus Linear Hashing *	291
10.5 Points to Review	292
Part IV QUERY EVALUATION	299
11 EXTERNAL SORTING	301
11.1 A Simple Two-Way Merge Sort	302
11.2 External Merge Sort	305
11.2.1 Minimizing the number of Runs *	308
11.3 Minimizing I/O Cost versus Number of I/Os	309
11.3.1 Blocked I/O	310
11.3.2 Double Buffering	311
11.4 Using B+ Trees for Sorting	312

11.4.1 Clustered Index	312
11.4.2 Unclustered Index	313
11.5 Points to Review	315
12 EVALUATION OF RELATIONAL OPERATORS	319
12.1 Introduction to Query Processing	320
12.1.1 Access Paths	320
12.1.2 Preliminaries: Examples and Cost Calculation	321
12.2 The Selection Operation	321
12.2.1 No Index, Unsorted Data	322
12.2.2 No Index, Sorted Data	322
12.2.3 B+ Tree Index	323
12.2.4 Hash Index, Equality Selection	324
12.3 General Selection Conditions *	325
12.3.1 CNF and Index Matching	325
12.3.2 Evaluating Selections without Disjunction	326
12.3.3 Selections with Disjunction	327
12.4 The projection Operation	329
12.4.1 Projection Based on Sorting	329
12.4.2 Projection Based on Hashing *	330
12.4.3 Sorting versus Hashing for Projections *	3332
12.4.4 Use of Indexes for Projections *	333
12.5 The Join Operation	333
12.5.1 Nested Loops Join	334
12.5.2 Sort-Merge Join *	339
12.5.3 Hash Join *	343
12.5.4 General Join Conditions *	348
12.6 The Set Operations *	349
12.6.1 Sorting for Union and Difference	349
12.6.2 Hashing for Union and Difference	349
12.7 Aggregate Operations *	350
12.7.1 Implementing Aggregation by Using an Index	351
12.8 The Impact of Buffering *	352
12.9 Points to Review	353
13 INTRODUCTION TO QUERY OPTIMIZATION	359
13.1 Overview of Relational Query Optimization	360
13.1.1 Query Evaluation Plans	361
13.1.2 Pipelined Evaluation	362
13.1.3 The Iterator Interface for Operators and Access Methods	363
13.1.4 The System R Optimizer	364
13.2 System Catalog in a Relational DBMS	365
13.2.1 Information Stored in the System Catalog	365
13.3 Alternative Plans: A Motivating Example	368
13.3.1 Pushing Selections	368
13.3.2 Using Indexes	370
13.4 Points to Review	373
14 A TYPICAL RELATIONAL QUERY OPTIMIZER	374
14.1 Translating SQL Queries into Algebra	375
14.1.1 Decomposition of a Query into Blocks	375
14.1.2 A Query Block as a Relational Algebra Expression	376
14.2 Estimating the Cost of a Plan	378
14.2.1 Estimating Result Sizes	378

14.3 Relational Algebra Equivalences	383
14.3.1 Selections	383
14.3.2 Projections	384
14.3.3 Cross-Products and Joins	384
14.3.4 Selects, Projects, and Joins	385
14.3.5 Other Equivalences	387
14.4 Enumeration of Alternative Plan	387
14.4.1 Single-Relation Queries	387
14.4.2 Multiple-Relation Queries	392
14.5 Nested Subqueries	399
14.6 Other Approaches to Query Optimization	402
14.7 Points to Review	403

## Part V DATABASE DESIGN 415

### 15 SCHEMA REFINEMENT AND NORMAL FORMS 417

15.1 Introduction to Schema Refinement	418
15.1.1 Problems Caused by Redundancy	418
15.1.2 Use of Decompositions	420
15.1.3 Problems Related to Decomposition	421
15.2 Functional Dependencies	422
15.3 Examples Motivating Schema Refinement	423
15.3.1 Constraints on an Entity Set	423
15.3.2 Constraints on a Relationship Set	424
15.3.3 Identifying Attributes of Entities	424
15.3.4 Identifying Entity Sets	426
15.4 Reasoning about Functional Dependencies	427
15.4.1 Closure of a Set of FDs	427
15.4.2 Attribute Closure	429
15.5 Normal Forms	430
15.5.1 Boyce-Codd Normal Form	430
15.5.2 Third Normal Form	432
15.6 Decompositions	434
15.6.1 Lossless-Join Decomposition	435
15.6.2 Dependency-Preserving Decomposition	436
15.7 Normalization	438
15.7.1 Decomposition into BCNF	438
15.7.2 Decomposition into 3NF *	440
15.8 Other Kinds of Dependencies *	444
15.8.1 Multivalued Dependencies	445
15.8.2 Fourth Normal Form	447
15.8.3 Join Dependencies	449
15.8.4 Fifth Normal Form	449
15.8.5 Inclusion Dependencies	449
15.9 Points to Review	450

### 16 PHYSICAL DATABASE DESIGN AND TUNING 457

16.1 Introduction to Physical Database Design	458
16.1.1 Database Workloads	458
16.1.2 Physical Design and Tuning Decisions	459
16.1.3 Need for Database Tuning	460
16.2 Guidelines for Index Selection	460
16.3 Basic Examples of Index Selection	463
16.4 Clustering and Indexing *	465

16.4.1 Co-clustering Two Relations	468
16.5 Indexes on Multiple-Attribute Search Keys *	470
16.6 Indexes that Enable Index-Only Plans *	471
16.7 Overview of Database Tuning	474
16.7.1 Tuning Indexes	474
16.7.2 Tuning the Conceptual Schema *	475
16.7.3 Tuning Queries and Views	476
16.8 Choices in Tuning the Conceptual Schema *	477
16.8.1 Settling for a Weaker Normal Form	478
16.8.2 Denormalization	478
16.8.3 Choice of Decompositions	479
16.8.4 Vertical Decomposition	480
16.8.5 Horizontal Decomposition	481
16.9 Choices in Tuning Queries and Views *	482
16.10 Impact of Concurrency *	484
16.11 DBMS Benchmarking *	485
16.11.1 Well-Known DBMS Benchmarks	486
16.11.2 Using a Benchmark	486
16.12 Points to Review	487
 17 SECURITY	497
17.1 Introduction to Database Security	497
17.2 Access Control	497
17.3 Discretionary Access Control	498
17.3.1 Grant and Revoke on Views and Integrity Constraints *	506
17.4 Mandatory Access Control *	508
17.4.1 Multilevel Relations and Polyinstantiation	510
17.4.2 Covert Channels, DoD Security Levels	511
17.5 Additional Issues Related to Security *	512
17.5.1 Role of the Database Administrator	512
17.5.2 Security in Statistical Databases	513
17.5.3 Encryption	514
17.6 Points to Review	517

## Part VI TRANSACTION MANAGEMENT 521

18 TRANSACTION MANAGEMENT OVERVIEW	523
18.1 The concept of a Transaction	523
18.1.1 Consistency and Isolation	525
18.1.2 Atomicity and Durability	525
18.2 Transactions and Schedules	526
18.3 Concurrent Execution of Transactions	527
18.3.1 Motivation for Concurrent Execution	527
18.3.2 Serializability	528
18.3.3 Some Anomalies Associated with Interleaved Execution	528
18.3.4 Schedules Involving Aborted Transactions	531
18.4 Lock-Based Concurrency Control	532
18.4.1 Strict Two-Phase Locking (Strict 2PL)	532
18.5 Introduction to Crash Recovery	533
18.5.1 Stealing Frames and Forcing Pages	535
18.5.2 Recovery-Related Steps during Normal Execution	536
18.5.3 Overview of ARIES	537
18.6 Points to Review	537

19 CONCURRENCY CONTROL	540
19.1 Lock-Based Concurrency Control Revisited	540
19.1.1 2PL, Serializability, and Recoverability	540
19.1.2 View Serializability	543
19.2 Lock Management	543
19.2.1 Implementing Lock and Unlock Requests	544
19.2.2 Deadlocks	546
19.2.3 Performance of Lock-Based Concurrency Control	548
19.3 Specialized Locking Techniques	549
19.3.1 Dynamic Databases and the Phantom Problem	550
19.3.2 Concurrency Control in B+ Trees	551
19.3.3 Multiple-Granularity Locking	554
19.4 Transaction Support in SQL-92 *	555
19.4.1 Transaction Characteristics	556
19.4.2 Transactions and Constraints	558
19.5 Concurrency Control without Locking	559
19.5.1 Optimistic Concurrency Control	559
19.5.2 Timestamp-Based Concurrency Control	561
19.5.3 Multiversion Concurrency Control	563
19.6 Points to Review	564
20 CRASH RECOVERY	571
20.1 Introduction to ARIES	571
20.1.1 The Log	573
20.1.2 Other Recovery-Related Data Structures	576
20.1.3 The Write-Ahead Log Protocol	577
20.1.4 Checkpointing	578
20.2 Recovering from a System Crash	578
20.2.1 Analysis Phase	579
20.2.2 Redo Phase	581
20.2.3 Undo Phase	583
20.3 Media Recovery	586
20.4 Other Algorithms and Interaction with Concurrency Control	587
20.5 Points to Review	588
Part VII ADVANCED TOPICS	595
21 PARALLEL AND DISTRIBUTED DATABASES	597
21.1 Architectures for Parallel Databases	598
21.2 Parallel Query Evaluation	600
21.2.1 Data Partitioning	601
21.2.2 Parallelizing Sequential Operator Evaluation Code	601
21.3 Parallelizing Individual Operations	602
21.3.1 Bulk Loading and Scanning	602
21.3.2 Sorting	602
21.3.3 Joins	603
21.4 Parallel Query Optimization	606
21.5 Introduction to Distributed Databases	607
21.5.1 Types of Distributed Databases	607
21.6 Distributed DBMS Architectures	608
21.6.1 Client-Server Systems	608
21.6.2 Collaborating Server Systems	609
21.6.3 Middleware Systems	609
21.7 Storing Data in a Distributed DBMS	610
21.7.1 Fragmentation	610



21.7.2 Replication	611
21.8 Distributed Catalog Management	611
21.8.1 Naming Objects	612
21.8.2 Catalog Structure	612
21.8.3 Distributed Data Independence	613
21.9 Distributed Query Processing	614
21.9.1 Nonjoin Queries in a Distributed DBMS	614
21.9.2 Joins in a Distributed DBMS	615
21.9.3 Cost-Based Query Optimization	619
21.10 Updating Distributed Data	619
21.10.1 Synchronous Replication	620
21.10.2 Asynchronous Replication	621
21.11 Introduction to Distributed Transactions	624
21.12 Distributed Concurrency Control	625
21.12.1 Distributed Deadlock	625
21.13 Distributed Recovery	627
21.13.1 Normal Execution and Commit Protocols	628
21.13.2 Restart after a Failure	629
21.13.3 Two-Phase Commit Revisited	630
21.13.4 Three-Phase Commit	632
21.14 Points to Review	632
 22 INTERNET DATABASES	642
22.1 The World Wide Web	643
22.1.1 Introduction to HTML	643
22.1.2 Databases and the Web	645
22.2 Architecture	645
22.2.1 Application Servers and Server-Side Java	647
22.3 Beyond HTML	651
22.3.1 Introduction to XML	652
22.3.2 XML DTDs	654
22.3.3 Domain-Specific DTDs	657
22.3.4 XML-QL: Querying XML Data	659
22.3.5 The Semistructured Data Model	661
22.3.6 Implementation Issues for Semistructured Data	663
22.4 Indexing for Text Search	663
22.4.1 Inverted Files	665
22.4.2 Signature Files	666
22.5 Ranked Keyword Searches on the Web	667
22.5.1 An Algorithm for Ranking Web Pages	668
22.6 Points to Review	671
 23 DECISION SUPPORT	677
23.1 Introduction to Decision Support	678
23.2 Data Warehousing	679
23.2.1 Creating and Maintaining a Warehouse	680
23.3 OLAP	682
23.3.1 Multidimensional Data Model	682
23.3.2 OLAP Queries	685
23.3.3 Database Design for OLAP	689
23.4 Implementation Techniques for OLAP	690
23.4.1 Bitmap Indexes	691
23.4.2 Join Indexes	692
23.4.3 File Organizations	693

23.4.4 Additional OLAP Implementation Issues	693
23.5 Views and Decision Support	694
23.5.1 Views, OLAP, and Warehousing	694
23.5.2 Query Modification	695
23.5.3 View Materialization versus Computing on Demand	696
23.5.4 Issues in View Materialization versus Computing on Demand	696
23.6 Finding Answers Quickly	699
23.6.1 Top N Queries	700
23.6.2 Online Aggregation	701
23.7 Points to Review	702

## 24 DATA MINING 707

24.1 Introduction to Data Mining	707
24.2 Counting Co-occurrences	708
24.2.1 Frequent Itemsets	709
24.2.2 Iceberg Queries	711
24.3 Mining for Rules	713
24.3.1 Association Rules	714
24.3.2 An Algorithm for Finding Association Rules	714
24.3.3 Association Rules and ISA Hierarchies	715
24.3.4 Generalized Association Rules	716
24.3.5 Sequential Patterns	717
24.3.6 The Use of Association Rules for Prediction	718
24.3.7 Bayesian Networks	719
24.3.8 Classification and Regression Rules	720
24.4 Tree-Structured Rules	722
24.4.1 Decision Trees	723
24.4.2 An Algorithm to Build Decision Trees	725
24.5 Clustering	726
24.5.1 A Clustering Algorithm	728
24.6 Similarity Search over Sequences	729
24.6.1 An Algorithm to Find Similar Sequences	730
24.7 Additional Data Mining Tasks	731
24.8 points to Review	732

## 25 OBJECT-DATABASE SYSTEMS 736

25.1 Motivating Example	737
25.1.1 New Data Types	738
25.1.2 Manipulating the New Kinds of Data	739
25.2 User-Defined Abstract Data Types	742
25.2.1 Defining Methods of an ADT	743
25.3 Structured Types	744
25.3.1 Manipulating Data of Structured Types	745
25.4 Objects, Object Identity, and Reference Types	748
25.4.1 Notions of Equality	749
25.4.2 Dereferencing Reference Types	750
25.5 Inheritance	750
25.5.1 Defining Types with Inheritance	751
25.5.2 Binding of Methods	751
25.5.3 Collection Hierarchies, Type Extents, and Queries	752
25.6 Database Design for an ORDBMS	753
25.6.1 Structured Types and ADTs	753
25.6.2 Object Identity	756
25.6.3 Extending the ER Model	757

25.6.4 Using Nested Collections	758
25.7 New Challenges in Implementing an ORDBMS	759
25.7.1 Storage and Access Methods	760
25.7.2 Query Processing	761
25.7.3 Query Optimization	763
25.8 OODBMS	756
25.8.1 The ODMG Data Model and ODL	765
25.8.2 OQL	
25.9 Comparing RDBMS with OODBMS and ORDBMS	769
25.9.1 RDBMS versus ORDBMS	
25.9.2 OODBMS versus ORDBMS: Similarities	770
25.9.3 OODBMS versus ORDBMS: Differences	770
25.10 Points to Review	771
 26 SPATIAL DATA MANAGEMENT	777
26.1 Types of Spatial Data and Queries	777
26.2 Applications Involving Spatial Data	779
26.3 Introduction to Spatial Indexes	781
26.3.1 Overview of Proposed Index Structures	782
26.4 Indexing Based on Space-Filling Curves	783
26.4.1 Region Quad Trees and Z-Ordering: Region Data	784
26.4.2 Spatial Queries Using Z-Ordering	785
26.5 Grid Files	786
26.5.1 Adapting Grid Files to Handle Regions	789
26.6 R Trees: Point and Region Data	789
26.6.1 Queries	790
26.6.2 Insert and Delete Operations	792
26.6.3 Concurrency Control	793
26.6.4 Generalized Search Trees	794
26.7 Issues in High-Dimensional Indexing	795
26.8 Points to Review	795
 27 DEDUCTIVE DATABASES	799
27.1 Introduction to Recursive Queries	800
27.1.1 Datalog	801
27.2 Theoretical Foundations	803
27.2.1 Least Model Semantics	804
27.2.2 Safe Datalog Programs	805
27.2.3 The Fixpoint Operator	806
27.2.4 Least Model = Least Fixpoint	807
27.3 Recursive Queries with Negation	808
27.3.1 Range-Restriction and Negation	809
27.3.2 Stratification	809
27.3.3 Aggregate Operation	812
27.4 Efficient Evaluation of Recursive Queries	813
27.4.1 Fixpoint Evaluation without Repeated Inferences	814
27.4.2 Pushing Selections to Avoid Irrelevant Inferences	816
27.5 Points to Review	818
 28 ADDITIONAL TOPICS	822
28.1 Advanced Transaction Processing	822
28.1.1 Transaction Processing Monitors	822
28.1.2 New Transaction Models	823
28.1.3 Real-Time DBMSs	824

28.2 Integrated Access to Multiple Data Sources	824
28.3 Mobile Databases	825
28.4 Main Memory Databases	825
28.5 Multimedia Databases	826
28.6 Geographic Information Systems	827
28.7 Temporal and Sequence Databases	828
28.8 Information Visualization	829
28.9 Summary	829

## A DATABASE DESIGN CASE STUDY: THE INTERNET SHOP 831

A.1 Requirements Analysis	831
A.2 Conceptual Design	832
A.3 Logical Database Design	832
A.4 Schema Refinement	835
A.5 Physical Database Design	836
A.5.1 Tuning the Database	838
A.6 Security	838
A.7 Application Layers	840

## B THE MINIBASE SOFTWARE 842

B.1 What's Available	842
B.2 Overview of Minibase Assignments	843
B.2.1 Overview of Programming Projects	843
B.2.2 Overview of Nonprogramming Assignments	844
B.3 Acknowledgments	845

## REFERENCES 847

## SUBJECT INDEX 879

## AUTHOR INDEX 896