CONTENTS

PR	EFA	CE	xxii
Par	t I	BASICS	1
1	IN	TRODUCTION 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	TH	E ENTITY-RELATIONSHIP MODEL	24
	2.1	Overview of Database Design	24
		2.1.1 Beyond the ER Model	25
	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	45
3	TH	E 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	85
Pai	rt II	RELATIONAL QUERIES	89
4	\mathbf{RE}	LATIONAL ALGEBRA AND CALCULUS	91
	4.1	Preliminaries	91
	4.2	Relational Algebra	92
		4.2.1 Selection and Projection	93
		4.2.2 Set Operations	94
		4.2.3 Renaming	96
		4.2.4 Joins	97
		4.2.5 Division	99
		4.2.6 More Examples of Relational Algebra Queries	100

Contents ix

5

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
\mathbf{SQ}	L: QUERIES, PROGRAMMING, TRIGGERS	119
5.1	About the Examples	121
5.2	The Form of a Basic SQL Query	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 *	147
	5.6.1 Comparisons Using Null Values	147
	5.6.2 Logical Connectives AND, OR, and NOT	148
	5.6.3 Impact on SQL Constructs	148
	5.6.4 Outer Joins	149
	5.6.5 Disallowing Null Values	150
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 Bo 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	$\mathbf{Q}\mathbf{U}$	VERY-BY-EXAMPLE (QBE)	177
	6.1	Introduction	177
	6.2	Basic QBE Queries	178
		6.2.1 Other Features: Duplicates, Ordering Answers	179
	6.3	Queries over Multiple Relations	180
	6.4	Negation in the Relation-Name Column	181
	6.5	Aggregates	181
	6.6	The Conditions Box	183
		6.6.1 And/Or Queries	184
	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
Pa	rt III	I DATA STORAGE AND INDEXING	193
7	ST	ORING 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	200
		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	Page Formats *	218
		7.6.1 Fixed-Length Records	218
		7.6.2 Variable-Length Records	219
	7.7	Record Formats *	221

Contents xi

		7.7.1 Fixed-Length Records	222
		7.7.2 Variable-Length Records	222
	7.8	Points to Review	224
8	FIL	E 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	TR	EE-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	HA	SH-BASED INDEXING	278
	10.1	Static Hashing	278
		10.1.1 Notation and Conventions	280
	10.2	Extendible Hashing *	280
	10.3	Linear Hashing *	286
	10.4	Extendible Hashing versus Linear Hashing *	291
	10.5	Points to Review	292

Par	rt IV	QUERY EVALUATION	299
11	$\mathbf{E}\mathbf{X}'$	TERNAL SORTING	301
	11.1		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	\mathbf{EV}	ALUATION OF RELATIONAL OPERATORS	319
	12.1	Introduction to Query Processing	320
		12.1.1 Access Paths	320
		12.1.2 Preliminaries: Examples and Cost Calculations	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 *	332
		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	350
	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
	12.0	Tomos to recview	000
13	INT	TRODUCTION 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	ΑТ	YPICAL 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 Plans	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
Paı	rt V	DATABASE DESIGN	415
15	SCI	HEMA REFINEMENT AND NORMAL FORMS	417
τŋ		Introduction to Schema Refinement	417
	15.1		418
		15.1.1 Problems Caused by Redundancy	418
		15.1.2 Use of Decompositions 15.1.2 Problems Polated to Decomposition	420
	15.0	15.1.3 Problems Related to Decomposition	421
	15.2	Functional Dependencies Every les Medienting Scheme Refinement	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	РΗ	YSICAL 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

ContentsXV

		16.8.5 Horizontal Decomposition	48
	16.9	Choices in Tuning Queries and Views *	48
	16.10	Impact of Concurrency *	48
		DBMS Benchmarking *	48
		16.11.1 Well-Known DBMS Benchmarks	48
		16.11.2 Using a Benchmark	48
	16.12	Points to Review	48
17	SEC	CURITY	49
	17.1	Introduction to Database Security	49
	17.2	Access Control	49
	17.3	Discretionary Access Control	49
		17.3.1 Grant and Revoke on Views and Integrity Constraints *	50
	17.4	Mandatory Access Control *	50
		17.4.1 Multilevel Relations and Polyinstantiation	51
		17.4.2 Covert Channels, DoD Security Levels	51
	17.5	Additional Issues Related to Security *	51
		17.5.1 Role of the Database Administrator	51
		17.5.2 Security in Statistical Databases	51
		17.5.3 Encryption	51
	17.6	Points to Review	51
Par	rt ${f VI}$	TRANSACTION MANAGEMENT	52
Par		TRANSACTION MANAGEMENT ANSACTION MANAGEMENT OVERVIEW	52 52
	TR	ANSACTION MANAGEMENT OVERVIEW	52
	TR	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction	52 52
	TR	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation	52 52 52
	TR . 18.1	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability	52 52 52 52
	TR. 18.1	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules	52 52 52 52 52
	TR. 18.1	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions	52 52 52 52 52 52
	TR. 18.1	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution	52 52 52 52 52 52 52
	TR. 18.1	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability	52 52 52 52 52 52 52 52
	TR 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions Lock-Based Concurrency Control	52 52 52 52 52 52 52 52 52
	TR 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions	52 52 52 52 52 52 52 52 52 52
	TR 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions Lock-Based Concurrency Control	52 52 52 52 52 52 52 52 52 52 53
	TR. 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions Lock-Based Concurrency Control 18.4.1 Strict Two-Phase Locking (Strict 2PL)	52 52 52 52 52 52 52 52 52 53 53
	TR. 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions Lock-Based Concurrency Control 18.4.1 Strict Two-Phase Locking (Strict 2PL) Introduction to Crash Recovery	52 52 52 52 52 52 52 52 52 53 53 53
	TR. 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions Lock-Based Concurrency Control 18.4.1 Strict Two-Phase Locking (Strict 2PL) Introduction to Crash Recovery 18.5.1 Stealing Frames and Forcing Pages	52 52 52 52 52 52 52 52 53 53 53 53
	TR. 18.1 18.2 18.3	ANSACTION MANAGEMENT OVERVIEW The Concept of a Transaction 18.1.1 Consistency and Isolation 18.1.2 Atomicity and Durability Transactions and Schedules Concurrent Execution of Transactions 18.3.1 Motivation for Concurrent Execution 18.3.2 Serializability 18.3.3 Some Anomalies Associated with Interleaved Execution 18.3.4 Schedules Involving Aborted Transactions Lock-Based Concurrency Control 18.4.1 Strict Two-Phase Locking (Strict 2PL) Introduction to Crash Recovery 18.5.1 Stealing Frames and Forcing Pages 18.5.2 Recovery-Related Steps during Normal Execution	52 52 52 52 52 52 52 52 53 53 53 53

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	CR	ASH 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
Pai	rt VI	I ADVANCED TOPICS	595
21	DA.	RALLEL AND DISTRIBUTED DATABASES	505
4 1			597
	21.1	Architectures for Parallel Databases	598
	21.2	Parallel Query Evaluation	600
		21.2.1 Data Partitioning	601
	01.0	21.2.2 Parallelizing Sequential Operator Evaluation Code	601
	21.3	Parallelizing Individual Operations	602
		21.3.1 Bulk Loading and Scanning	602

Contents

xvii

		21.3.2 Sorting	602
		21.3.3 Joins	603
	21.4	Parallel Query Optimization	600
	21.5	Introduction to Distributed Databases	60'
		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	61
	21.8	Distributed Catalog Management	61
		21.8.1 Naming Objects	613
		21.8.2 Catalog Structure	613
		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	61.
		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	62^{2}
	21.12	Distributed Concurrency Control	628
		21.12.1 Distributed Deadlock	628
	21.13	Distributed Recovery	62'
		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	633
	21.14	Points to Review	632
22	INT	TERNET 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	64
		22.2.1 Application Servers and Server-Side Java	64'
	22.3	Beyond HTML	65
		22.3.1 Introduction to XML	652
		22.3.2 XML DTDs	65^{2}
		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	\mathbf{DE}	CISION 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	698
	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	$\mathbf{D}\mathbf{A}'$	TA 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

Contents

xix

		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	ОВ	JECT-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	765
		25.8.1 The ODMG Data Model and ODL	765
		25.8.2 OQL	768
	25.9	Comparing RDBMS with OODBMS and ORDBMS	769
		25.9.1 RDBMS versus ORDBMS	769
		25.9.2 OODBMS versus ORDBMS: Similarities	770
		25.9.3 OODBMS versus ORDBMS: Differences	770

	25.10	Points to Review	771
26	\mathbf{SP}^{A}	ATIAL 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 Operations	812
	27.4		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

Contents	xxi

	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
\mathbf{A}	$\mathbf{D}\mathbf{A}'$	TABASE DESIGN CASE STUDY: THE INTERNET	Γ
	\mathbf{SH}	OP	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
В	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
RE	EFER	RENCES	847
SU	BJE	CT INDEX	879
ΑŪ	J TH (OR INDEX	896