

PRINCIPLES OF DATABASE SYSTEMS

ABOUT THE BOOK

In recent years an extensive body of theory and general principles related to database systems has been developed. For the first time a comprehensive treatment of this material is now offered. Description of actual data-base systems and query languages such as ISBL, QUEL, Query-by-Example, and SEQUEL are also included, making this book ideal for both practicing computer scientists and for database courses. Security and concurrency are covered in separate chapters.

ABOUT THE AUTHOR

Jeffrey D. Ullman received his B.S. degree from Columbia University and his Ph.D. from Princeton University in 1966. He was at Bell Laboratories in Murry Hill, New Jersey for three year prior to joining the faculty at Princeton University. He taught there from 1969-79. Currently, he is a Professor of Computer Science at Stanford University. Dr. Ullman is the Data-base Editor of *JACM* as well as serving on the editorial staff of *SIAM Journal of Computing*, *JCSS* and *TCS*.

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Jeffrey D. Ullman

 **GALGOTIAS**

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THIRD EDITION

Jeffrey D. Ullman

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PREFACE TO THE FIRST EDITION

It is evident that a course in database systems now plays a central role in the undergraduate and graduate programs in computer science. However, unlike the more traditional and better established systems areas, like compilers and operating systems, where a good mix of principles and practice was established many years ago, the subject matter in database systems has been largely descriptive.

This book is developed from notes I used in a course at Princeton that attempted to bring database systems into the mainstream of computer science. The course was taught to a mix of seniors and first-year graduate students. In it, I tried to relate database ideas to concepts from other areas, such as programming languages, algorithms, and data structures. A substantial amount of descriptive material was included, since students, being used to conventional programming languages, may find query languages rather unusual. The data structures relevant to databases are also somewhat different from the kinds of structures used in conventional programming, since the large scale of a database makes practical many structures that would be only of theoretical interest otherwise.

However, I added to the mix of topics the relevant theory that is now available. The principal concepts that have been found useful are concerned with relations and with concurrency. I have devoted a large portion of the book to a description of relations, their algebra and calculus, and to the query languages that have been designed using these concepts. Also included is an explanation of how the theory of relational databases can be used to design good systems, and a description of the optimization of queries in relation-based query languages. A chapter is also devoted to the recently developed protocols for guaranteeing consistency in databases that are operated on by many processes concurrently.

Exercises

Each chapter includes exercises to test basic concepts and, in some cases, to extend the ideas of the chapter. The most difficult exercises are marked with a double star, while problems of intermediate difficulty have a single star.

Acknowledgments

I am grateful for the comments and suggestions I received from Al Aho, Brenda Baker, Peter deJong, Ron Fagin, Vassos Hadzilacos, Zvi Kedem, Hank Korth, and Joseph Spinden. The initial draft of this manuscript was ably typed by Gerree Pecht. Her efforts and the support facilities at Princeton University are appreciated.

J. D. U.

**PREFACE TO THE SECOND EDITION**

The appearance of a large number of interesting and important developments in the database field prodded me to make a substantial revision of the book. The general direction of changes is towards more prominence for the relational model and systems based on that model. I have therefore simplified the material on the hierarchical and network models; however, I brought it up to the front of the book, so there will be some slight tendency for that material to be covered in a course of limited scope, as it should be. The other major changes to the book are the following.

1. The material on optimization has been expanded, by including a discussion of the System R approach to optimization, tableau-based methods, and optimization in the distributed environment.
2. There is a discussion of universal relation systems, which are relational database systems that support a user view that looks like a single relation.
3. Concurrency control by "optimistic," or timestamp-based methods has been introduced.
4. Distributed systems are covered, both for optimization issues and concurrency control.
5. A discussion of data structures for range queries appears.
6. There is an introduction to generalized dependencies and their inference.

Mapping the Old Edition to the New

Those familiar with the first edition will notice that some material has been moved around. A brief guide for finding the transplanted material follows.

Material from the old Chapters 1 and 2 is still there, along with some additional material. The old Chapter 3 has been split up. Introductory material from there now appears in Chapter 1, while some material on the network model (Section 3.2) has been combined with the old Chapter 7 to form the new Chapter 3. Section 3.3 on the hierarchical model has been combined with some of the material from the old Chapter 8 to form the new Chapter 4. Some of the IMS-specific material from Chapter 8 has been removed.

Chapter 4, on the relational model, has been divided into Chapters 5 and 6. Chapter 5 now contains relational algebra and calculus, and all the material on physical organization for relational systems. The query languages themselves are described in Chapter 6. The old Section 3.4, comparing the

various models, now appears in Chapter 5. The old chapters 5, 6, 9, and 10 have been renumbered 7, 8, 10, and 11, and some new material added.

About the Cover

It's a "data baste," get it? No? Uh, well, the chef has this bulb baster, see, and ... , aw, forget it.

More Acknowledgements

The following people made comments on the first edition or made suggestions that were helpful in the preparation of the second edition: Dan Blosser, Martin Brooks, Mary Feay, Shel Finkelstein, Kevin Karplus, Arthur Keller, Keith Lantz, Dave Maier, Dan Newman, Mohammed Olumi, Shuky Sagiv, Charles Shub, and Joe Skudlarek. Their thoughts are much appreciated.

The second edition was prepared using Don Knuth's TEX typesetting system. I would also like to thank Luis Trabb-Pardo for invaluable assistance debugging my attempts to use the system.

J. D. U.

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