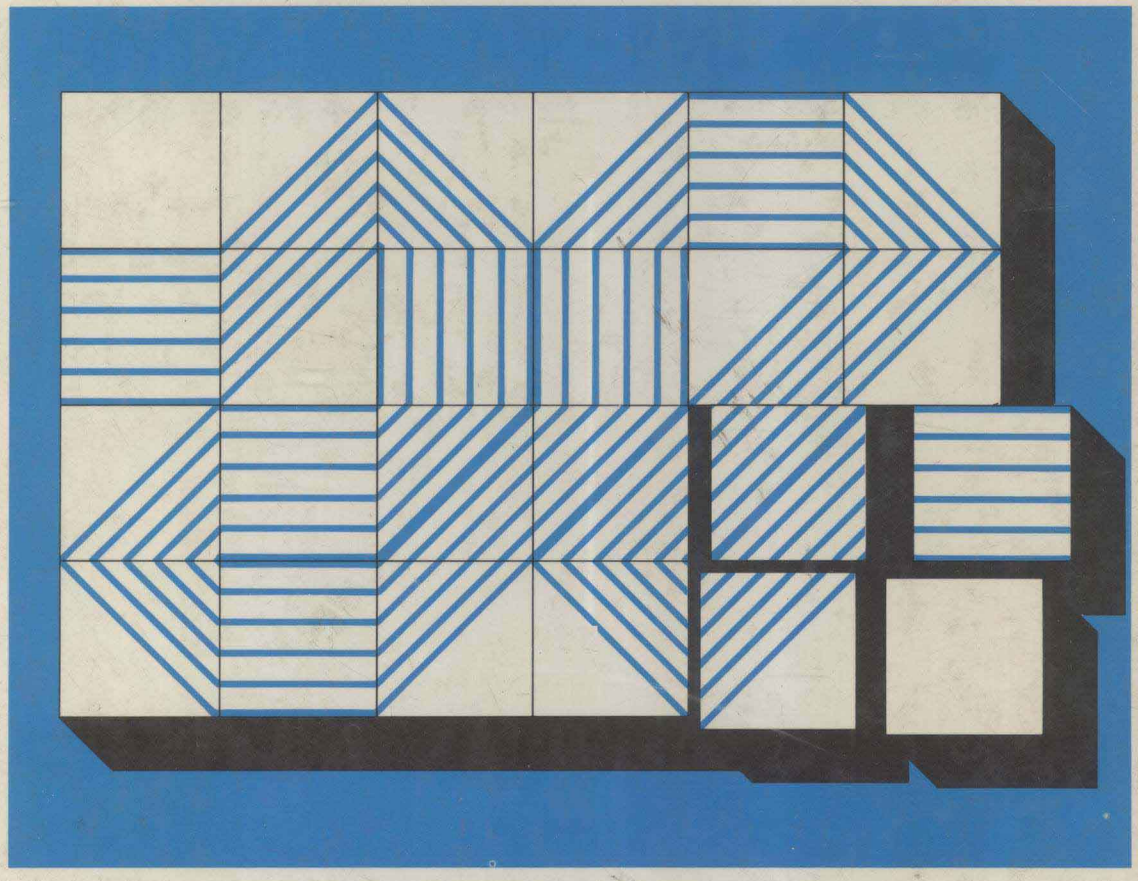
Operating Systems

Advanced Concepts

Maekawa • Oldehoeft • Oldehoeft



Operating Systems

ADVANCED CONCEPTS

Mamoru Maekawa
University of Tokyo
Arthur E. Oldehoeft
Iowa State University
Rodney R. Oldehoeft
Colorado State University

THE BENJAMIN/CUMMINGS PUBLISHING COMPANY, INC.

Menlo Park, California • Reading, Massachusetts
Don Mills, Ontario • Wokingham, U.K. • Amsterdam
Sydney • Singapore • Tokyo • Madrid • Bogota
Santiago • San Juan

Sponsoring Editor: Alan Apt
Production Editors: Laura Kenney, Julie Kranhold
Copyeditor: Carol Dondrea
Illustrator: Lisa Torri
Cover Designer: John Edeen
Compositor: Graphic Typesetting Service

The basic text of this book was designed using the Modular Design System, as developed by Wendy Earl and Design Office Bruce Kortebein.

Library of Congress Cataloging-in-Publication Data

Maekawa, M. (Mamoru), 1942-
Operating systems.

Includes bibliographies and index.
1. Operating systems (Computers) I. Oldehoeft, Arthur E. II. Oldehoeft, Rodney R. III. Title.
QA76.76.063M335 1987 005.4'3 86-28419
ISBN 0-8053-7121-4

BCDEFGHIJ-DO-8 987

The Benjamin/Cummings Publishing Company, Inc.
2727 Sand Hill Road
Menlo Park, CA 94025

Operating Systems

ADVANCED CONCEPTS

Preface

The study of computer operating systems has progressed from learning an ad hoc collection of folk wisdom about how systems work to examining a coherent set of topics about which substantial theoretical and practical knowledge has been developed. We have been teaching modern operating systems to undergraduates and graduate students for 10 to 15 years at several universities, and believe that introductory material for the undergraduate student is well agreed upon and adequately exposited in several modern texts.

Unfortunately, at the graduate-student or professional level, no such agreement exists. Worse, to teach advanced material properly we have been forced to rely directly on the current literature. Although reference to the contemporary work of researchers and practitioners is useful at this level, students (and instructors as well) have felt the lack of a centralized source of information upon which to rely for an overall framework and source of direction.

The purpose of this book is to provide that needed resource. We have identified eight major subjects in the design and analysis of modern operating systems and have brought together our work on each topic to give the reader a modern course in the advanced topics of importance. The synthesis of many points of view gives the reader an accurate picture of the current state of each topic. The subjects are enduring ones that are not dependent on a particular vendor's system or on current technology; this material should be useful in design and analysis of future systems as well.

Operating Systems: Advanced Concepts continues to rely on original sources for two reasons. First, to keep the book to a manageable size, some subjects are covered completely at a fundamental level with references to generalizations and special cases that the interested reader may pursue. Second, we believe that at this level the serious student of operating systems must be cognizant of the contemporary literature; we hope this approach will help train the reader in professional reading habits if they are not already established. To make this easy, we have often chosen to refer to the most accessible items of literature (major journal or conference articles) instead of the earliest sources (often internal technical reports). In addition to cited references, we provide an additional bibliography of literature for each topic.

Our appreciation is due to Misses Noriko Shiogama and Nahoko Murao, who entered the first handwritten version of the manuscript. The following reviewers have carefully read and improved the book through several drafts: Imtiaz Ahmad, University of Windsor; Rob Cubert, Sacramento State University; D. M. Etter, University of New Mexico; William Franta, University of Minnesota; Dale Grit, Colorado State University; Teofilo Gonzales, University of Texas at Dallas; Evan Ivie,

Brigham Young University; Roger King, University of Colorado; Marek Rusinkiewicz, University of Houston; and Nish Thakor, Northwestern University. Many students in our operating classes have been exposed to this material and have selflessly pointed out areas for clarification and improvement. All of these people have made this an enjoyable project and, we hope, a valuable product. Finally, we would like to acknowledge our families and friends who have provided support and encouragement over the course of the project.

Mamoru Maekawa
Arthur E. Oldehoeft
Rodney R. Oldehoeft

Acknowledgments

Figure 3.12 is reprinted from *Ada for Experienced Programmers* by A. Nico Habermann and Dwane E. Perry (Addison-Wesley, 1983).

Figures 6.21 and 6.22 and Tables 6.3 and 6.4 are reprinted from Mamoru Maekawa, "A *N* Algorithm for Mutual Exclusion in Decentralized Systems," in *ACM Transactions on Computer Systems* 3 (May 1985). Reprinted by permission of the Association for Computing Machinery, Inc.

Figure 8.24 is reprinted from Voydock and Kent, "Security Mechanisms in High-Level Network Protocols," in *Computing Surveys* 15 (1983). Reprinted by permission of the Association for Computing Machinery, Inc.

Contents

Overview 1

1.1 Introduction

The purpose of this book is to serve as a resource in the advanced study of modern computer operating systems. The book can be used in at least three ways. First, it can serve as a textbook in a formal course in advanced operating systems for students who have mastered fundamental material in an undergraduate course. We include here advanced-level material on familiar topics (synchronization, deadlock, virtual memory), as well as material that is not generally covered at an elementary level (security, distributed systems and control, modeling and analysis). There is enough material for a two-quarter sequence, and more than enough for a single semester. There are numerous questions and problems. The former will help students review the chapter; the latter should help them delve more deeply into the material of each chapter. Each chapter also includes a list of important terms to help ensure subject mastery.

Second, the book is useful as an organized course for professionals or for self-study. The chapters are organized so that a brief but adequate review precedes material at an advanced level. This will allow the professional whose background is strong but incomplete to quickly "come up to speed" on a particular subject. Where appropriate, references are given to background material that may be valuable for the reader who is working independently.

Third, the book is a guide to current research and methodology for operating system designers. The individual chapters are independent of each other and well suited for the reader who wants to study a particular subject in depth.

The chapters each center on a major topic in the advanced study of operating systems. The following briefly describes the contents of each chapter. The references in this chapter are the basis on which most significant topics in this book are based.

1.2 Chapter 2: Process Synchronization

In this chapter we cover methods for process management that are more advanced than those found in an introductory course. After a brief review of processes and their synchronization via elementary methods, we describe a model that is valuable for analyzing sets of concurrent processes [Bernstein, 1966]. With this model we can demonstrate safe, deterministic execution while ensuring the maximum potential for parallel processing. Advanced methods of process synchronization are surveyed